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U. S. DEPARTMENT OF AGRICULTURE.

OFFICE OF EXPERIMENT STATIONS—BULLETIN NO. 134.

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STORAGE OF WATER ON CACHE LA POUDRE AND BIG THOMPSON RIVERS.

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BY

C. E. TAIT,

ASSISTANT IN IRRIGATION INVESTIGATIONS.

WASHINGTON:
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1903.

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MAP OF CACHE LA POUDRE AND BIG THOMPSON RIVERS SHOWING DRAINAGE BASINS, IRRIGATED LAND AND MOUNTAIN RESERVOIRS

SCALE OF MILES 0 5 10 15

IRRIGATED LAND

MAP SHOWING RESERVOIRS ON CACHE LA POUDRE AND BIG THOMPSON RIVERS COLORADO

SCALE OF MILES 0 1 2 3 4 5

607

U. S. DEPARTMENT OF AGRICULTURE.

OFFICE OF EXPERIMENT STATIONS—BULLETIN NO. 134.

A. C. TRUE, Director.

STORAGE OF WATER ON CACHE LA POUDRE AND BIG THOMPSON RIVERS.

BY

C. E. TAIT,

ASSISTANT IN IRRIGATION INVESTIGATIONS.

WASHINGTON:

GOVERNMENT PRINTING OFFICE.

1903.

OFFICE OF EXPERIMENT STATIONS.

A. C. True, Ph. D., *Director.*
E. W. Allen, Ph. D., *Assistant Director.*

IRRIGATION INVESTIGATIONS.

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C. T. Johnston, *Assistant Chief in Charge of Central District.*
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C. E. Tait, *Assistant in Charge of Maps and Illustrations.*

LETTER OF TRANSMITTAL.

U. S. Department of Agriculture,
Office of Experiment Stations,
Washington, D. C., August 1, 1903.

Sir: I have the honor to transmit herewith and to recommend for publication as a bulletin of this Office a report on the storage of water on the Cache la Poudre and Big Thompson rivers in northern Colorado, prepared under the direction of Prof. Elwood Mead, chief of irrigation investigations, by C. E. Tait, assistant in these investigations.

Respectfully,

A. C. True,
Director.

Hon. James Wilson,
Secretary of Agriculture.

LETTER OF SUBMITTAL.

U. S. Department of Agriculture,
Office of Experiment Stations,
Irrigation Investigations,
Washington, D. C., August 1, 1903.

Sir: I have the honor to submit for publication a report on the storage of water on the Cache la Poudre and Big Thompson rivers, prepared by Mr. C. E. Tait, assistant in irrigation investigations. The ground covered by this report has been partly gone over in previous reports of this Office, but the supply of some of these reports has been exhausted and, moreover, considerable progress has been made since their publication; it has, therefore, seemed advisable to issue a bulletin showing the results of a more thorough study of these valleys with reference to the storage of water and the use of the stored water in irrigation, going more fully into methods and details of construction than in the former bulletins, and giving much new data regarding the crop returns which are directly attributable to the use of stored water.

Northern Colorado is one of the most advanced agricultural sections in the arid region, and the value of water has led to the construction of reservoirs to store all the water the streams supply in ordinary years, and also of what may be termed "flood reservoirs," to catch the occasional floods which visit the valleys. This work has all been done by the farmers living in the valleys and has been extremely profitable, as is shown by the report. As development proceeds similar conditions will arise in other parts of the West, and the experience gained in Colorado will be suggestive and helpful to irrigators in the newer districts.

Respectfully,

Elwood Mead,
Chief of Irrigation Investigations.

Dr. A. C. True, *Director.*

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STORAGE OF WATER ON CACHE LA POUDRE AND BIG THOMPSON RIVERS.

By C. E. Tait,
Assistant in Irrigation Investigations.

INTRODUCTION.

The purpose of this report is to show the success and value of storage works, constructed by private capital and operated as private enterprises, and to describe the methods employed in their operation in order to encourage and aid the further extension of this form of irrigation development.

With the exception of the fruit districts in southern California, probably in no place is there as scientific and profitable a use of the water available for irrigation as in parts of Colorado. A study has been made of the storage on two streams in the north-central portion of the State—the Cache la Poudre and Big Thompson rivers—where an advanced stage of development has been reached. At present nearly all the water of these two streams not used for direct irrigation is stored, and if progress continues for a few years practically all of it will be used. This has been effected by the construction of numerous reservoirs, comparatively small or medium in size, entirely with private capital, by the irrigators themselves, who now control and operate their own works.

The aim of the report is to show how the farmers proceeded and to present the faults and merits of their plans as brought out by the test of usage, that their experience may benefit others in similar undertakings. The more general and popular questions of storage have been much discussed, but with little reference to the details of construction and operation. An attempt, therefore, was made to collect information regarding all the details of construction, the dimensions of dams and outlets, the efficiency of the works, and the legal conditions of storage, which might be of value to those unfamiliar with such work.

The results in agricultural products for the seasons of 1901 and 1902 are reported. The crops of the former year were slightly above the average, while those of the latter were below it on account of one of the smallest water supplies of which there is any record, and other

unfavorable conditions. When considered together, the results of the two seasons give at least a conservative idea of the value of the reservoirs of northern Colorado.

Only the larger and more important reservoirs on the Cache la Poudre are described, but all on the Big Thompson, regardless of size, were included in the investigation. While the small reservoirs owned by one or more farmers are not specially interesting studied individually, when considered together they show the great extent to which they are used and how they serve the needs of the irrigators. That practical irrigators should use this only partially satisfactory means of securing late water where there are no suitable sites for larger reservoirs supplementing the whole system is in itself convincing evidence of the value of stored water.

CHARACTER OF THE CACHE LA POUDRE AND BIG THOMPSON RIVERS.

The Cache la Poudre and Big Thompson rivers are the most important tributaries of the South Platte River. They drain a portion of north-central Colorado. The former drains about 1,000 square miles in the mountainous region east of the Medicine Bow and Laramie ranges and the latter about 600 square miles between the foothills and the Continental Divide. In the mountainous district the main streams are made up of innumerable streams, but there are few tributaries of importance east of the foothills. The headwaters of the Cache la Poudre are divided into three large branches—the Middle, North, and South forks. What is known as the Big South Poudre is an important stream entering the Middle Fork below Chambers Lake. The Big Thompson is formed by the North and South forks, the latter receiving Fall River. The Little Thompson enters the Big Thompson a few miles above where the latter enters the South Platte and is practically an independent stream as regards irrigation, for there are no ditches of importance below the junction. The Little Thompson is small and no measurements are made on it by the State. Its flow during the summer is made up mainly from seepage from the lands irrigated from the Big Thompson.

Both rivers, receiving their waters from the snows in the mountains, are, like all streams of this character, subject to great fluctuation. The following tables give the average daily discharges of the two streams for the years 1901 and 1902 and the average monthly discharges for the years 1895 to 1902, inclusive. The measurements for the years 1901 and 1902 were furnished by the water commissioners on the streams, while the average monthly discharges for former years were obtained from the reports of the State engineer.

Discharge of Cache la Poudre River in 1901.

Day.	March.	April.	May.	June.	July.	August.	September.	October.	November.
	Cu. feet per sec.	*Cu. feet per sec.*	*Cu. feet per sec.*	*Cu. feet per sec.*	*Cu. feet per sec.*	*Cu. feet per sec.*	*Cu. feet per sec.*	*Cu. feet per sec.*	*Cu. feet per sec.*
1	95	122	700	2,449	1,253	306	256	106	111
2	99	127	758	2,263	1,274	307	242	103	111
3	99	127	790	2,199	1,274	295	242	101	112
4	79	142	717	2,010	1,140	295	237	104	103
5	80	132	649	1,870	999	298	220	106	111
6	109	117	667	1,875	924	286	174	98	101
7	109	150	771	1,733	804	337	179	108	113
8	108	160	737	1,904	714	374	199	109	110
9	110	165	735	2,240	631	442	183	130	110
10	110	205	772	2,060	965	372	184	149	110
11	95	190	1,097	2,135	812	363	179	136	105
12	100	205	1,132	1,854	887	341	173	144	106
13	100	190	1,217	1,753	727	300	169	138	100
14	100	190	1,352	1,823	297	295	168	116	95
15	101	190	1,590	2,127	657	252	154	106	95
16	96	190	1,740	2,123	595	243	125	109	95
17	101	190	1,975	2,049	508	229	127	109	97
18	106	205	2,180	1,940	495	258	136	109	95
19	106	225	2,410	1,970	494	225	135	110	92
20	106	225	2,620	1,913	465	317	136	114	78
21	106	315	3,850	1,997	408	245	121	118	75
22	106	390	5,100	2,087	400	243	131	111	81
23	101	475	2,460	2,144	378	232	120	104	83
24	101	575	2,008	2,136	362	210	125	112	95
25	102	575	2,236	2,065	357	215	113	111	101
26	107	550	2,321	1,795	458	210	118	109	101
27	112	560	2,422	1,675	410	236	113	110	98
28	112	560	2,500	1,575	400	260	106	111	91
29	107	590	2,570	1,497	368	254	106	105	90
30	117	710	2,216	1,362	352	249	109	112	85
31	127	.....	2,574	.....	332	254	.....	109	.....
Average	103	292	1,770	1,954	650	282	159	113	98

The flow for December, January, and February is estimated at 75 cubic feet per second.

Discharge of Cache la Poudre River in 1902.

Day.	January.	February.	March.	April.	May.	June.	July.	August.	September.	October.	November.	December.
	Cu. ft. per sec.	*Cu. ft. per sec.*	*Cu. ft per sec.*	*Cu. ft. per sec.*	*Cu. ft. per sec.*	*Cu. ft. per sec.*	*Cu. ft. per sec.*	*Cu. ft. per sec.*	*Cu. ft. per sec.*	*Cu. ft. per sec.*	*Cu. ft. per sec.*	*Cu. ft. per sec.*
1	115	63	50	74	200	1,823	595	229	141	215	127	94
2	100	68	71	90	267	1,736	484	199	152	229	132	84
3	100	69	70	89	336	1,558	467	203	138	226	102	89
4	110	68	62	110	366	1,455	491	196	115	228	103	87
5	105	74	58	100	509	1,660	417	192	80	200	102	117
6	110	73	65	110	553	1,512	417	200	76	194	107	127
7	112	78	65	114	583	1,526	374	194	75	199	102	127
8	115	78	70	134	700	1,644	303	187	72	187	105	117
9	95	83	100	135	824	1,623	370	180	72	183	123	127
10	80	83	86	139	897	1,618	372	179	83	183	125	132
11	70	88	74	144	1,042	1,635	353	175	80	162	120	129
12	55	85	70	163	1,143	1,420	314	164	68	162	120	120
13	54	95	73	145	1,370	1,386	349	158	68	168	133	115
14	60	95	78	159	1,269	1,296	244	156	68	163	134	115
15	57	90	80	154	1,548	1,159	200	161	64	163	123	120
16	70	85	39	157	1,502	947	257	152	63	210	128	120
17	80	90	65	165	1,438	917	241	131	68	210	128	107
18	65	91	62	170	1,470	873	378	131	66	177	137	122
19	75	96	84	216	1,281	854	412	126	69	171	137	120
20	90	90	89	240	1,108	793	349	114	71	167	139	122
21	80	71	79	274	887	758	285	117	126	170	137	115
22	76	76	82	175	662	754	253	104	488	170	131	140
23	61	65	85	149	656	724	238	99	478	170	115	140
24	63	62	89	155	603	779	224	109	322	168	126	125
25	63	66	101	162	681	606	271	109	293	170	96	110
26	64	60	100	179	892	604	267	104	241	147	101	135
27	68	78	102	179	1,302	743	276	94	240	154	121	125
28	63	74	103	146	1,521	712	255	109	270	152	126	130
29	63	.....	99	156	1,566	707	245	112	258	147	108	112
30	64	.....	99	191	1,407	729	235	91	256	132	84	87
31	62	.....	104	.....	1,887	.....	243	94	.....	132	.....	92
Average.	79	78	79	152	983	1,152	328	147	155	178	119	116

Average monthly discharge of Cache la Poudre River, 1895–1902.

Year.	March.	April.	May.	June.	July.	August.	September.	October.	November.
	Cu. feet per sec.	*Cu. feet per sec.*	*Cu. feet per sec.*	*Cu. feet per sec.*	*Cu. feet per sec.*	*Cu. feet per sec.*	*Cu. feet per sec.*	*Cu. feet per sec.*	*Cu. feet per sec.*
1895	.....	.....	1,437	2,497	1,130	495	224	.....	.....
1896	.....	.....	.....	773	458	272	292	.....	.....
1897	.....	727	2,105	1,739	749	371	177	.....	.....
1898	.....	306	671	1,330	481	184	78	59	.....
1899	.....	.....	1,486	2,632	1,441	557	212	117	.....
1900	.....	1,376	2,809	2,942	721	265	149	132	.....
1901	103	292	1,829	1,954	682	282	159	113	98
1902	79	153	983	1,152	328	147	155	178	119
Average	91	571	1,617	1,877	749	322	181	120	109
Average discharge in acre-feet	5,595	33,977	99,426	111,689	46,055	19,799	10,770	7,379	6,486

Discharge of Big Thompson River in 1901.

Day.	June.	July.	August.	September.	October.	Day.	June.	July.	August.	September.	October.
	Cu. ft. per sec.	*Cu. ft. per sec.*	*Cu. ft. per sec.*	*Cu. ft. per sec.*	*Cu. ft. per sec.*		*Cu. ft. per sec.*	*Cu. ft. per sec.*	*Cu. ft. per sec.*	*Cu. ft. per sec.*	*Cu. ft. per sec.*
1	.....	975	255	110	45	18	616	425	255	55	45
2	.....	975	255	110	45	19	710	225	220	55	45
3	.....	851	255	95	45	20	810	355	220	55	45
4	.....	811	355	110	45	21	864	355	255	55	45
5	643	741	355	95	44	22	990	355	275	55	55
6	620	725	355	95	44	23	1,092	308	220	55	55
7	626	583	355	110	45	24	1,143	308	180	55	55
8	865	557	355	110	45	25	1,127	308	180	44	55
9	944	557	506	110	45	26	882	355	150	44	55
10	1,260	761	506	80	45	27	864	355	180	44	55
11	980	864	404	80	55	28	810	308	140	44	55
12	895	761	370	80	55	29	810	308	140	44	55
13	870	710	355	80	55	30	790	308	140	44	55
14	900	608	255	70	55	31	.....	255	140	.....	55
15	910	557	275	70	55						
16	740	557	220	60	55	Average	865	534	269	72	50
17	740	425	220	60	55						

Discharge of Big Thompson River in 1902.

Day.	April.	May.	June.	July.	August.	September.	October.	November.
	Cu. feet per sec.	*Cu. feet per sec.*	*Cu. feet per sec.*	*Cu. feet per sec.*	*Cu. feet per sec.*	*Cu. feet per sec.*	*Cu. feet per sec.*	*Cu. feet per sec.*
1	.....	80	710	308	110	55	110	35
2	.....	80	659	263	110	55	220	35
3	.....	80	557	308	110	55	140	35
4	.....	80	659	308	143	55	180	35
5	.....	80	761	263	143	45	110	35
6	.....	110	659	220	110	45	110	35
7	.....	143	659	180	110	45	90	30
8	.....	180	761	150	110	45	80	30
9	.....	220	761	143	110	33	80	30
10	.....	220	810	180	80	33	80	35
11	.....	263	761	180	80	33	110	35
12	.....	308	659	180	80	33	180	35
13	.....	404	608	180	80	33	140	35
14	.....	506	608	180	110	33	140	28
15	.....	506	659	180	110	33	110	28
16	.....	506	659	180	80	28	110	35
17	.....	557	557	180	80	28	80	40
18	.....	557	506	455	80	28	110	35
19	.....	506	455	355	80	28	80	28
20	.....	263	455	220	70	35	80	28
21	.....	220	404	180	55	180	80	30
22	.....	180	404	180	55	263	55	30
23	.....	143	404	180	55	220	55	35
24	.....	143	455	180	80	143	55	35
25	35	143	455	143	80	110	55	35
26	35	143	455	308	55	220	40	30
27	35	404	455	180	55	143	40	30
28	35	659	455	143	55	143	55	30
29	35	455	506	120	55	143	55	.....
30	35	659	404	110	80	110	40	.....
31	.....	710	.....	110	55	.....	35	.....
Average	35	307	577	208	86	82	94	33

Average monthly discharge of Big Thompson River, 1895–1902.

Year.	April.	May.	June.	July.	August.	September.	October.	November.
	Cu. feet per sec.	*Cu. feet per sec.*	*Cu. feet per sec.*	*Cu. feet per sec.*	*Cu. feet per sec.*	*Cu. feet per sec.*	*Cu. feet per sec.*	*Cu. feet per sec.*
1895	.....	318	570	465	319	146	79	.....
1896	37	218	285	225	144	119	66	.....
1897	.....	420	465	267	133	37	17	27
1898	.....	164	377	238	79	36	13	8
1899	140	303	917	653	283	92	64	.....
1900	412	1,382	1,362	349	137	77	.....	.....
1901	.....	.....	865	534	269	72	50	.....
1902	35	307	517	208	81	82	94	32
Average	156	445	670	367	181	83	55	22
Average discharge in acre-feet	9,282	27,362	39,867	22,566	11,129	4,938	3,382	1,309

THE NECESSITY FOR STORAGE.

The first ditches on the Cache la Poudre were constructed about 1860. The Union Colony came to Greeley in 1870 and the first of the larger canals were constructed about this time. At first grains and hay only were raised, but after several experiments it was found that potatoes, when rotated with alfalfa and the cereals, were especially adapted to the soil in the valleys, and on account of the greater profit in them they soon became the crop on which the farmers depended for their cash returns. One by one the canals were constructed until the flow of the rivers failed to meet the demand and there was no water for the later ditches after the middle of July.

As long as wheat was the main crop all was well, for it required the water early in the season when there was an abundance of it, but since the vegetables and alfalfa have become the main crops water is needed at a time when the floods in the streams are over. From October 1, the end of the irrigation season, to May 1 the comparatively small flow of the streams remains nearly constant. The streams then begin to rise and the greatest discharge of the year comes with the first warm days in May or June, when the snows in the mountains are melting. After the few days of the flood season the discharge of the streams rapidly decreases until by the middle of July, the time for the first irrigation of potatoes, the ordinary low stage is reached, and the flow seldom if ever increases during the irrigation season. Potatoes require water from the middle of July to September, and the preceding tables show how the streams fail during that time.

On July 15, 1901, the Cache la Poudre River furnished 657 cubic feet per second and its discharge gradually decreased throughout the rest of the irrigation season; but on June 15, one month before, the river had furnished 2,127 cubic feet per second, and on May 15 its discharge was 1,590 cubic feet per second. The daily discharge from May 11 to July 4 was over 1,000 cubic feet per second, and on June 22 it reached 5,100 cubic feet per second; but after July 15 it did not on a single day reach 600 cubic feet per second. In 1902 it was found that the same stream was flowing at the rate of only 200 cubic feet per second on July 15, when it was necessary to irrigate potatoes and sugar beets, while on June 15 the discharge was 1,159 cubic feet per second. From May 11 to 20 and from May 27 to June 15 the discharge did not fall below 1,000 cubic feet per second. The table giving the average monthly discharge of the river for eight years shows a striking contrast between the months of May and June and those following.

In 1901 the discharge of the Big Thompson from June 8 to July 6 did not fall below 700 cubic feet per second, and on four days during

this time was above 1,000 cubic feet per second; but from July 15 to October 1 the discharge varied from 557 cubic feet per second to 44 cubic feet per second, and was over 400 cubic feet per second on only seven days during this time. In 1902 there was less snow in the mountains than usual to supply the streams, and the discharge at all times during the year was far below the average. From May 28 to June 18 the flow was not below 500 cubic feet per second, the highest stage being on June 10, when the flow measured 810 cubic feet per second. From July 15 to September 20 the flow exceeded 200 cubic feet per second on four days only. The average for May in cubic feet per second was 307; for June, 577; while for July it was only 208, and for August only 86. The average discharge of the Big Thompson for the past eight years in May is 445 cubic feet per second; in June, 670 cubic feet per second; while for July it is 367 cubic feet per second; for August, 181 cubic feet per second, and for September only 83 cubic feet per second. This means that the average amount furnished by the stream in May is 27,362 acre-feet and in June 39,845 acre-feet; while in July it falls to 22,566 acre-feet, in August to 11,129 acre-feet, and in September it is only 4,937 acre-feet.

With these conditions the farmers soon found that no matter how much water the streams furnished in the early part of the season it was of no benefit to them in maturing their valuable crops, which require water in the latter part of the season. They saw the floods in May or June and their crops suffering for want of water in July and August. The necessity of storage confronted them in a most realistic manner, and the first ventures were made in 1881, when a reservoir was constructed in each of the valleys under discussion. From that time the development in storage, and with it the wealth and prosperity of the country, has progressed steadily until at present the valleys are dotted with numerous reservoirs, varying in size from the smallest pond furnishing water to a single farm, to the large reservoirs of the cooperative companies of farmers irrigating thousands of acres. Potatoes, cabbage, and onions, were raised with great success, and recently sugar beets, which are very similar to potatoes as regards their requirements for water, have been introduced and have added greatly to the demand for stored water.

Progress has not been delayed even by the unusual season of 1902, when the supply of the streams failed to fill the reservoirs already constructed, and works are now being built which their owners expect to fill only every two or three years, knowing from experience that their investments are safe.

The map (frontispiece) gives a better idea of the great number of these reservoirs than can be obtained in any other way.

RESERVOIRS ON CACHE LA POUDRE RIVER.

CACHE LA POUDRE RESERVOIR.

The Cache la Poudre Reservoir Company was organized in 1892 and its reservoir was constructed the same year. In organizing this company the stockholders were limited to those owning stock in the Cache la Poudre Irrigating Company and land under its canal, the Cache la Poudre No. 2, and those owning land that could be irrigated from the reservoir. It was specified that only one share could be taken in the reservoir company for each share in the canal company. While the reservoir and canal companies are entirely distinct organizations, the stockholders are nearly identical excepting a few in the reservoir company who are irrigators under the Lake Canal. There are 3,000 shares of stock in the Cache la Poudre Reservoir Company and 375 rights, 8 shares constituting one 80-acre water right.

A certain number of shares of stock in the reservoir companies in the valley is taken as being equivalent to one water right. This number is determined in the following manner: The average farm consists of 80 acres, and as one right is intended to serve each farm the rights are known as 80-acre water rights. The reservoir water is almost always used on vegetables, and as 20 to 30 acres is the usual area planted in these crops on an 80-acre farm, the amount of water for 20 to 30 acres of vegetables is taken as the amount that it is desirable for an 80-acre water right to represent. The right usually represents 1,000,000 cubic feet, or about 22 acre-feet of stored water. The number of these rights is then limited by the capacity of the reservoir. Finally, the number of shares of stock to each 80-acre right is determined from the total number of shares in the capital stock.

The reservoir is situated 4 miles north of the canal and its outlet ditch runs almost directly south, entering the canal 1½ miles below the head gate. The basin of the reservoir was not a natural one originally containing some water, as was the case with those of so many in the valley, but was formed by constructing two embankments, one 2,000 feet long and 16 feet high along the southwest side, and the other one-half mile long and 36 feet high, along the south side. The latter crosses a narrow part of the shallow valley in which the reservoir is located. It settled 4 feet the first year after construction, but allowance had been made for at least as much settling. The outside slope of these dams is 2 to 1 and the inside slope 3 to 1. If the inside slope were continued to the top the dams would be only 4 feet wide on top, but a row of wooden piles was driven along the inside slope near the top and these planked up to form a support for the rock and earth which were filled in behind. This fill makes the dams 16 feet wide on top. The piles were driven 10 feet into the dam and extend 4 feet above, and as the

high-water line is 6 feet below the top of the dam this makes an excellent protection against the wave action during high winds when the reservoir is full. (Pl. II, fig. 1.) The inner faces of the dams were covered with gravel 2 feet thick, and then stone was laid on this 1 foot thick. The waves have disturbed the riprapping in places and the slope is now irregular. Before building the larger dam a trench 8 feet wide, 6 feet deep, and 1,000 feet long was dug along the lowest portion of the line where the dam was to be constructed. The trench was then refilled with fresh material as a protection against seepage under the dam.

The outlet is through the larger dam below its highest point. The ground being marshy it was necessary to make a very solid foundation. A cut 9 feet deep was made and filled 2 feet deep with cobble stones, which were packed by pounding with mauls. This layer was slushed with mortar, and rubble masonry was built up 5½ feet higher, all the openings being filled with mortar (fig. 1). This foundation for the outlet is 14 feet wide on the bottom, except at the two ends, where it is 20 feet wide. This outlet is a stone arch 5 feet high and 5 feet wide, with side walls 2½ feet thick, and has two collars built around it. The arch was made of some condemned curbstones, which were from 10 to 14 feet in length and 2 feet wide. Winged retaining walls 3 feet thick were constructed at both the upper and the lower ends of the outlet. For a short distance at the upper end of the outlet it is divided into two conduits, each of which is covered by a patent cast-iron gate. The mechanism is so arranged that when the gates are being operated they do not slide against their frames, but are carried by small wheels, which run on a track set at an angle of 20° from the vertical, and in this way much of the friction due to the great pressure of the water is obviated (fig. 2). Just before the gates reach their final position in closing they are dropped into place, where they should fit tightly against the frames at the upper end of the conduit. At the same time the weight is taken from the wheels and they are lifted from the track. This is accomplished by turning the shafts carrying the wheels, which are slightly eccentric. In fig. 2 the gate is shown in its position when closed, while the dotted lines indicate the position when the gate is slightly lifted from the frame, the wheels are raised from the track,

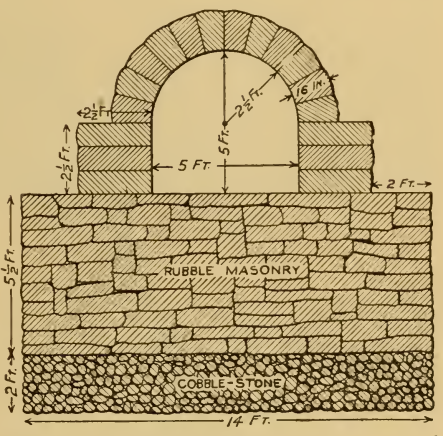


FIG. 1.—Cross section of masonry arch outlet of Cache la Poudre Reservoir.

and the entire mechanism is just ready to be run up the track. One of the gates would not open the first year the reservoir was used, and after many expensive attempts to open it a professional diver had to be employed, with whose assistance the difficulty was overcome. The gates have always leaked more or less, and in 1902 one of them could not be closed, the leakage for part of the time amounting to 29 cubic feet per second. While this water was not wasted, it is probable that the persons who used it would rather have had it at some other time. Theoretically the design of the gate is good, for the power required to move a gate running on wheels is much less than that required to move a

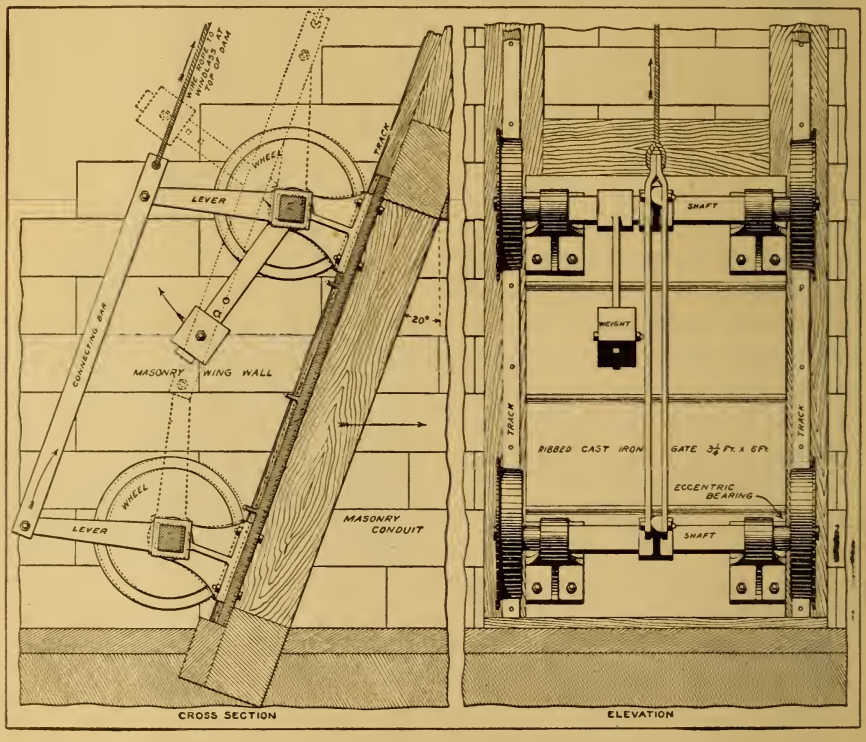


FIG. 2.—Design of gate used at Cache la Poudre Reservoir.

similar one which slides on a frame. However, the company has not found the gates to be practicable, and it is certain that any apparatus for the purpose should be simple, since it can not conveniently be reached under water. The gates are raised by wire ropes extending over the face and to the top of the dam, where a windlass gives multiplied power. They are closed by their own weight.

The reservoir is 600 acres in area and when full the water is 31 feet deep at the outlet. Its capacity is 350,000,000 cubic feet, or 8,035 acre-feet, which gives 21.43 acre-feet to each water right. It is filled entirely from the Cache la Poudre River through the inlet ditch, which is $5\frac{3}{4}$ miles long and has a capacity of 140 cubic feet per second.

FIG. 1.—PILING AND RIPRAPPING ON EMBANKMENT OF CACHE LA POUDRE.

FIG. 2.—MASONRY GATE WELL, LARIMER AND WELD RESERVOIR.

The reservoir has a decree dated March 12, 1892, entitling it to be filled 27 feet deep, and another dated August 4, 1894, which adds 3 feet to this depth. The sum of these two gives 374,000,000 cubic feet. The first of these decrees is preceded by those of the Windsor Reservoir and four reservoirs of the Water Supply and Storage Company. Its inlet is the lowest on the river except that of the Fossil Creek Reservoir, and the latter reservoir comes much the latest as regards the privilege of storage, so that Cache la Poudre Reservoir is entitled to all the water reaching its head gate not needed for direct irrigation. The gain in the river due to seepage is enough to increase the flow below the next head gate a considerable amount, and this benefits the reservoir. The seepage continues throughout all the seasons, and up to the present time has increased from year to year as the lands are becoming more and more saturated with water. The water used for power purposes by the Mason & Hottel mill at Fort Collins has been one of the main factors in filling the reservoir. The mill race is entitled to 60 cubic feet per second, which is returned to the river above the head of the inlet and below the head gates of all the large canals except two, the Cache la Poudre No. 2 and the Cache la Poudre No. 3, so that the reservoir company can use it for storage a part of the time. This water has been a bone of contention on the river, as it has been claimed by other canals and reservoirs. At one time it was used by the canals above when not needed by the mill, but by a decision of the State supreme court it must now be allowed to flow to the reservoir inlet continuously during the months of December, January, and February. This gives the company a good chance of filling its reservoir every year, and in 1902 it was the only one completely filled. The decision was based on the claim that for years this water went to waste during these winter months until it began to be stored by the reservoir company. The water is used for late irrigation from the middle of July to the last of September, and is measured by a weir and an automatic register of gage heights in the outlet ditch just below the dam. Weirs are also used in the laterals for measuring out each irrigator's proportional amount. The reservoir company pays the canal company $10 per right per annum for delivering the water. All the water is used through and under the Cache la Poudre Canal No. 2 except 35 rights that are owned by irrigators under the Lake Canal, lying above the Cache la Poudre No. 2. Before the reservoir was constructed the Lake Canal ran through what is now the reservoir basin, and the reservoir company turned the course of the canal around the south side through a deep and expensive cut. Before the gates of the reservoir can be opened the owners of at least 25 rights must call for either all or a part of their proportional amount of the stored water, since it is required that no less than 25 cubic feet per second can be turned out, and that each right shall receive water at the rate of 1 cubic foot per second. However, an exception is made in the case

of those 35 rights under the Lake Canal whereby a minimum run to them of one-half the specified amount is allowable. The reservoir rights are worth $650 each and the value of all of them is $243,750. The original cost of the reservoir was $105,000, or $13.07 per acre-foot of capacity, which includes the cost of the inlet and outlet ditches and the purchase of land. The construction alone cost $81,000. The expense of maintenance is $1,000 per annum.

LARIMER AND WELD RESERVOIR.

This reservoir is owned by the Larimer and Weld Reservoir Company, which is entirely distinct from the Larimer and Weld Irrigation Company, owning and operating the Larimer and Weld Canal. The canal was constructed many years before the reservoir. The stockholders in the canal company are the farmers using water from the canal, and a number of these organized the reservoir company, in which stockholders were limited to those of the irrigation company. However, not all of the stockholders of the irrigation company, took stock in the reservoir company. At present 744 shares have been sold, making 186 rights, 4 shares constituting a water right.

The reservoir was constructed in 1891 and enlarged to its present capacity in 1894. It occupies what was formerly called Terry Lake, a natural basin collecting seepage water from irrigated lands in the vicinity. In utilizing this basin a cut 20 feet deep, in which to build the outlet, was made through the rim of the natural basin at the south side, and an earthen embankment 12 feet high and 1¼ miles long was constructed along the same side. The dam is 15 feet wide on top, and both the inside and outside slopes are 3 to 1. Before building the dam the ground was plowed, so there would be no distinct seam between the dam and the original surface. The dam was constructed in layers, each being well packed, and its inner face was riprapped with stone. A long trench was dug at the base of the dam just inside the reservoir, and then refilled with earth, thus closing any prairie-dog holes and preventing seepage under the dam.

The outlet is 32 feet below the top of the dam, and the cut in which it was laid was closed with earth and packed before building the dam over it. The conduit for 65 feet from the upper end is a stone arch 5 feet high and 6 feet wide, which terminates in a masonry well at the inner edge of the top of the dam. The arch is built on a concrete base. The conduit below the well consists of two cement pipes 36 inches in diameter and 100 feet long, laid 8 inches apart, and having 8 inches of cement all around them. Stone collars were built around the pipes at intervals of 20 feet to prevent the water from creeping along the outside. At the extreme ends of the outlet retaining walls with wings were built across the cut, which was left open beyond.

The wall of the gate well, just back of the gates, was extended for 50 feet on each side as a protection against seepage. (Pl. II, fig. 2.)

There are two wooden gates, 42 inches square and 4 inches thick, which slide in wooden frames against the inner face of the lower wall of the well, each covering an opening into the cement pipes. They are controlled by iron stems reaching to the top of the well where the power is multiplied by means of a nut and wrench. The gates leak slightly during the irrigation season after they have been once opened, but when the reservoir is emptied in the fall the gates are carefully seated, and as the pressure increases with the filling of the reservoir they soon become tight.

The area of the reservoir is 470 acres, and 31 feet in depth of water is drawn off. The capacity is 300,000,000 cubic feet, or 6,887 acre-feet, which entitles the holder of each water right to 37.03 acre-feet.

The reservoir cost $69,978.31, or $10.17 per acre-foot of its capacity. The construction alone cost less than $25,000, the rest being due to the purchase of the site, cost of surveys, attorney's fees, and miscellaneous expenditures. In 1900 the price of a right was from $900 to $950; in 1901, from $1,200 to $1,300, and in 1902, from $1,200 to $1,400. Using $1,300 as the value of one right, the value of the reservoir is $241,800. The expense of maintenance is $600 per annum.

The reservoir is located just above the Larimer and Weld Canal, about 2 miles below its head gate, so that the stored water may be used directly through the canal. The canal company charges the reservoir company $1 per million cubic feet for carrying this water. When the reservoir was first constructed the canal company refused to carry the water from the reservoir through its canal, and litigation was resorted to by the reservoir company. The result was that the canal company was compelled to allow its canal to be used as a carrier upon payment of a charge by the reservoir company. It was the opinion of the court that new canals should not be constructed when an existing one would serve all purposes.

The inlet ditch from the Cache la Poudre River is 4½ miles long. As yet the reservoir has no decree, and other means of filling are relied upon mainly. Dry Creek, a tributary of the Cache la Poudre, crosses the inlet ditch just west of the reservoir, and while it is dry part of the year, it is subject to floods at times which furnish a large supply, and the water from seepage which filled Terry Lake before the reservoir was constructed helps to some extent.

The Larimer County Canal crosses Dry Creek above the crossing of the reservoir inlet, and after the construction of the reservoir difficulties arose regarding the rights to the waters of the creek. Suit was brought by the company against the Water Supply and Storage Company, in which it was held by the court that the right of the Larimer

and Weld Reservoir Company to the waters of the creek was prior to the appropriation by the Water Supply and Storage Company, and the former was allowed to divert water for filling and refilling the reservoir. The Water Supply and Storage Company was restrained from taking any water from the creek to the detriment of the reservoir, and if it diverted any when the reservoir was not full it was compelled to return the same amount to the creek above the crossing of the reservoir inlet, provided the amount did not exceed the capacity of the reservoir inlet. The company has also used a part of the excessive appropriation of the Little Cache la Poudre Ditch for filling its reservoir, and while it may be said that the filling has depended largely on chance, these sources never failed to supply enough until the year 1902, when there were only 24 feet of water in the basin, instead of the usual 31 feet.

The Little Cache la Poudre Ditch is one of the highest taking water from the main river. It was given a decree of 60.08 cubic feet per second, dated 1869, this being priority No. 31, and another of 20.42 cubic feet per second, dated 1873, making a total of 80.50 cubic feet per second. Owing to the small capacity of the ditch and the small area of land irrigated, only about 22 cubic feet per second is needed.

Of the 30 shares in this ditch 19 have been used for storage purposes by the Larimer and Weld Reservoir Company, some having been purchased and the use of others acquired by contract. In 1902 the water commissioner refused to permit this use of the water, and a suit was brought against that officer, into which a number of the irrigation companies of the valley were drawn. The Larimer and Weld Reservoir Company asked for a decree to fill its reservoir from the Cache la Poudre River, Dry Creek, Little Cache la Poudre Ditch, and Round Butte Ditch. The Cache la Poudre Irrigating Company claimed that a part of the Little Cache la Poudre Ditch had been abandoned, and that the Larimer and Weld Reservoir Company had no right to the water not needed by the ditch, as it constituted an extended use of the water, and that it should be returned to the river for those ditches having old appropriations. The decision rendered was that the reservoir company had no right to use the shares held by contract and that these contracts were void, but that title to those purchased was good. It was specified, however, that the reservoir should receive no more from Little Cache la Poudre Ditch than 1 cubic foot per second per share owned in the ditch, and that this amount could not be used for storage during the season of direct irrigation. This reduced the claim of the reservoir company to 9½ cubic feet per second. Originally the company claimed only the waste, seepage, and flood waters of Dry Creek, but in 1902 it was deprived of the latter during the irrigation season.

The company expects to have an additional source of supply for filling its reservoir next year. It has nearly finished the construction of

the Bob Creek Ditch, in the mountains 35 miles west of the reservoir, which will divert water from Bob Creek, a tributary of Nun Creek, which in turn is a tributary of the Laramie River, and carry it to Roaring Fork, a tributary of the Middle Fork of the Cache la Poudre River, and the water will finally be taken from the main river by the inlet ditch and stored in the reservoir. The completion of the ditch will cost only $1,000, and it is expected that it will be ready for the spring floods of 1903. The ditch has a capacity of 100 cubic feet per second. It is estimated that the additional amount secured in this way will vary from 20 to 100 cubic feet per second during the year.

The reservoir is partly filled during the winter and the supply is completed with the spring floods. In 1901 the first run was commenced on August 3 and the last one ended September 10, when the reservoir was empty. The water is measured over a weir in the outlet ditch and then each shareholder's proportional amount is measured to him at the head of his lateral. In 1902 the company bought 50,000,000 cubic feet of stored water from the Water Supply and Storage Company, paying $100 per 1,000,000 cubic feet.

WINDSOR RESERVOIR.

The Windsor Reservoir was constructed in 1892 and was the first of the larger reservoirs in the Cache la Poudre Valley to be used. It occupies two natural basins, and the work of construction consisted in making a cut to join them and building the embankment along the south side of the lower and southern basin to enlarge the capacity. This dam is located on a small ridge and the reservoir can be further enlarged by building the dam higher. The dam is one-half mile long and 16½ feet high, having slopes both inside and outside of 2½ to 1. It is 20 feet wide on top and is protected with brush weighted down with stone, but if it is ever built higher stone alone will probably be used. The dam was constructed in 1-foot layers, each being packed.

A cut 17½ feet deep and 8 feet wide in which to lay the outlet was made through the ridge along the south where the dam was to cross. The cut was through slate which was disintegrated near the surface. The bottom of the cut was filled with concrete 1 foot deep and this covered with 2 inches of cement on which were laid flagstones 6 inches thick to form the floor of the outlet. This conduit is a stone arch 4 feet wide and 5 feet high with walls 2 feet thick. The outlet required 500 wagonloads of gravel, 70 carloads of stone, and 364 barrels or 25,600 pounds of cement. A buttress or a wall with wings supporting it and the bank on either side was constructed at the upper end of the conduit. The wall is 34 feet high and 2½ feet thick, the wings being stepped down to nothing and making a horizontal angle with the wall of about 30 degrees.

The gate slides in an iron frame with flanges and has a wooden stem

8 by 10 inches extending to the top of the wall, where it is fitted with an iron rod carrying a nut. The nut is set in a wooden frame so that it can have a rotary motion only and is turned by a wooden lever 8 or 10 feet in length. (Pl. III, fig. 1.) The wooden gate which was used the first year swelled in the water and stuck in the frame, making it very hard to operate. It was replaced by a malleable cast-iron gate weighing 1,040 pounds.

The Windsor Reservoir is one of the two largest in the valley. Its area is 700 acres, and 30 feet of water can be drawn off. The outlet is 34 feet below the top of the dam, thus leaving 4 feet for safety. After the reservoir is drained some water remains below the level of the outlet, which is the case with nearly all of those reservoirs having natural basins. Its capacity is 11,708 acre-feet and its construction cost $50,000, making the cost per acre-foot only $4.27. Of the total cost $10,000 was for enlarging the inlet and constructing the outlet ditch and $20,000 for the purchase of land.

The reservoir is owned by the Windsor Reservoir and Canal Company, but prior to 1902 this ownership was only nominal, the reservoir being practically owned by ex-Governor B. H. Eaton, who constructed it. He had originally constructed the Larimer and Weld Canal to irrigate his own land lying under it. The reservoir is just below the canal, near the halfway point of its length, and is too low to benefit most of this land. However, it is above the Cache la Poudre Canal No. 2, and from their relative positions it should naturally be used in connection with this canal. The outlet ditch of the reservoir is 3 miles long and runs almost directly south, joining Cache la Poudre No. 2 about 6 miles below the head gate, thus allowing the reservoir water to be used through the canal advantageously. It can be run to the Cache la Poudre Canal No. 3, which is still lower and on the south side of the river. Therefore an exchange has been effected by which the lands above the reservoir are benefited by it. Water is run to one or both of the lower canals in exchange for the same amount diverted from the river above by the Larimer and Weld Canal, which covers the land the reservoir company desires to irrigate. The two lower canals are the only ones so situated that they can use water returned to the river from the Mason & Hottel mill, a supply which is useful in the exchange. It is sometimes necessary for the owner of the reservoir to furnish the mill with coal for steam power in order that the water may be diverted at the head gate of the Larimer and Weld Canal above the mill.

The stock of the Windsor Reservoir and Canal Company is divided into 1,000 shares, two of which constitute an 80-acre water right. In the winter of 1902, when the reservoir was empty, 300 rights were sold. Most of these were purchased by irrigators under the Cache la Poudre Canal No. 2 and the Cache la Poudre Canal No. 3, 60 rights

to be used under the latter. A few of them were bought by people who had no land on which to use the water, but who intended to rent the water annually as a source of revenue on their investment. The price paid for this three-fifths of the reservoir was $100,000, or $333.33 per right. The reservoir holds 23.42 acre-feet for each water right. This transfer will probably eliminate in part the exchange previously referred to.

The Windsor Reservoir is filled from the Cache la Poudre through the Larimer and Weld Canal. When the reservoir was constructed the canal was capable of carrying only about 750 cubic feet per second, the amount of its appropriation, and so the canal was enlarged to a capacity of 1,000 cubic feet per second from its head to the inlet gate of the reservoir. There were formerly two inlet gates, but one has now been taken out because the water dropping from it was cutting away the bank, endangering the lower bank of the canal. The construction of an inlet from the river to the reservoir, making it possible to store the water returned to the river by the mill at Fort Collins has been considered, but the plan has been dropped.

The Windsor Reservoir was given a decree dated July 8, 1890, entitling it to be filled to a depth of 22.4 feet, and another dated August, 1893, entitling it to be filled to a depth of 7.6 feet in addition. The sum of the amounts is 510,000,000 cubic feet. The first decree is preceded by those of Nos. 2, 3, and 4 and Chambers Lake of the Water Supply and Storage Company, so that until these have been satisfied the Windsor Reservoir can not be filled to the extent allowed in its first decree. Before filling is completed the Cache la Poudre Reservoir must be partially filled, as it has a decree antedating the second decree of the Windsor Reservoir. The chances of filling the reservoir are good, however, unless the year is an exceptional one, as was 1902, when the water was only 23 feet deep, the amount stored being 250,000,000 cubic feet, or 5,740 acre-feet.

The original owners of the Windsor Reservoir are constructing a system of ditches in the mountains, about 47 miles west of their reservoir, which will greatly increase the supply available for storage. In 1902 they had completed and used the Sand Creek or Divide Ditch, which is 1½ miles long and has a capacity of 250 cubic feet per second. It cost $1,500. The ditch diverts water from Sand Creek, a tributary of the Laramie River, and carries it over the divide into Sheep Creek, one of the small tributaries of the North Fork of the Cache la Poudre River. In 1901 the flow of Sand Creek at this point was measured and was found to vary between 6 and 240 cubic feet per second, and it is expected to furnish a good supply for storage in the Windsor Reservoir every year.. In 1902, however, the Sand Creek Ditch did not at any time carry over 31 cubic feet per second and the total amount supplied by it was 60,700,000 cubic feet, or an amount equal to one-eighth

of the capacity of the Windsor Reservoir. Water was run through the ditch from May 9 to July 10, inclusive, and from July 16 to 23, inclusive.

This supply drawn from the Laramie River will be reinforced by two other ditches, one of which, the Deadman Ditch, has been completed and will be used in 1903. It crosses Deadman Creek, a tributary of the Laramie River, and several other small creeks or draws, catching the flow of all of them and carrying it over the divide to Sand Creek, the water finally being taken by the Sand Creek Ditch. In 1903 the other of these ditches, called the Columbine Ditch, is to be constructed. It is planned to divert the flow of Columbine Creek, a tributary of Sand Creek, and discharge it into the North Fork of the Cache la Poudre River. It is 2½ miles long and the Deadman Ditch is 5 miles long. It is estimated that these two will furnish about the same amount as the Sand Creek Ditch each year. There are no interests on the head waters of these streams in Colorado, and therefore no objections to these diversions have been made in that State. But Laramie River and Sand Creek flow north into Wyoming, where both are used for irrigation. This plan of increasing the available amount of water for storage in the reservoirs of the Cache la Poudre Valley at the expense of the irrigation interests in Wyoming has been complained of and a suit is now pending in the United States court.

Water is used from the Windsor Reservoir in runs of several days each, when each right receives its share at the rate of 1 cubic foot per second, the aggregate number of days in the runs being determined by the amount of water in the reservoir.

The reservoir not being full in 1902, Mr. Eaton found it necessary to purchase water for his lands. The Water Supply and Storage Company furnished 35,000,000 cubic feet or 803 acre-feet, and the North Poudre Irrigation Company 10,000,000 cubic feet or 230 acre-feet. The price paid in each case was $100 per million cubic feet or $4.36 per acre-foot.

WATER SUPPLY AND STORAGE COMPANY'S SYSTEM.

The Water Supply and Storage Company owns Chambers Lake, Rocky Ridge Reservoir, Reservoirs Nos. 2, 3, and 4, Long Pond, Lindenmeier Lake, and Curtis Lake. The company owns also the Larimer County Canal, and the Laramie River, Cameron Pass, and Grand River ditches. Chambers Lake and the three ditches are in the mountains at the head waters of the Cache la Poudre River. All the other reservoirs, except Curtis Lake, are embraced in a chain beginning with Rocky Ridge Reservoir on the north and ending with Lindenmeier Lake on the south. Rocky Ridge Reservoir is located 6 miles directly north of Fort Collins, and Nos. 2, 3, and 4 are to the south of

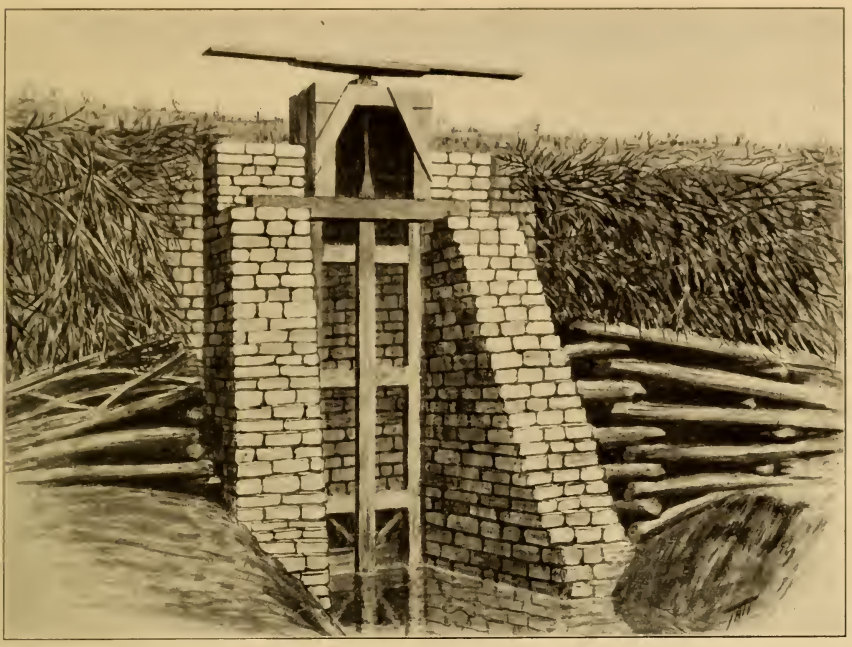


FIG. 1.—OUTLET AND BRUSH RIPRAPPING ON EMBANKMENT, WINDSOR RESERVOIR.

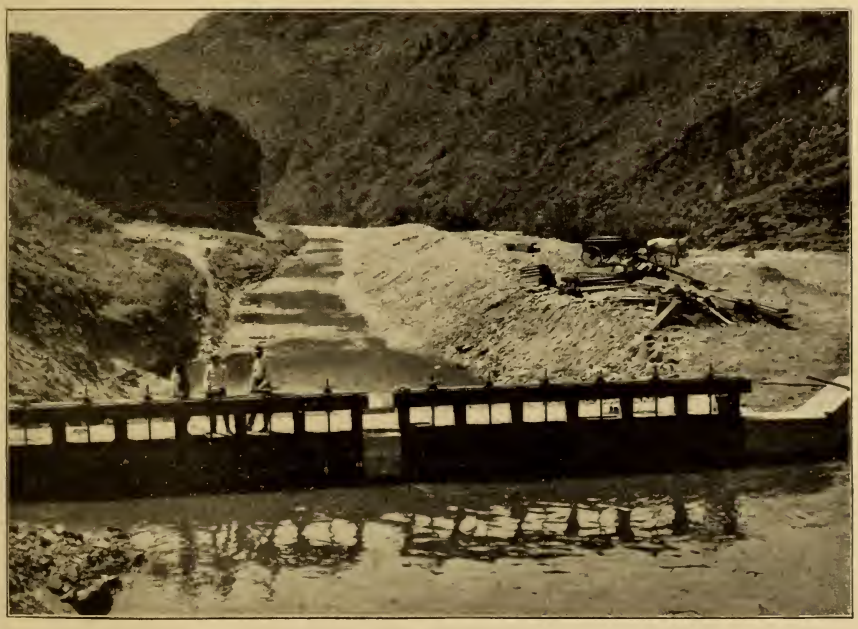


FIG. 2.—HEAD WORKS OF POUDRE VALLEY CANAL, INLET TO DOUGLAS RESERVOIR.

it in the order named. They are closely connected and one discharges into the other. The outlet ditch from No. 4 runs southeast about 2 miles and enters Long Pond, which discharges into Lindenmeier Lake, one-half mile south of it. Curtis Lake, in Dry Creek Valley, is 1½ miles west of No. 1.

ROCKY RIDGE RESERVOIR.

Rocky Ridge Reservoir, which is No. 1 of the system, is so called by reason of its location near a small and rocky ridge in the valley. It is just north but below the grade of the Larimer County Canal. The only embankment required was across a draw at the southeast end of the basin. This fill is 17 feet high, 60 feet wide on top, and 620 feet long, and the Larimer County Canal runs along the top of it. Its upper face is supported by a masonry wall having a slight batter, while the lower side is given a natural slope.

The outlet is a tunnel through the slight ridge along which the canal runs on the southwest side (fig. 3). The tunnel is 179 feet in length, and the 50 feet above the gate well is 3 feet wide and 4 feet high. Below the well it is only 2 feet wide and 3 feet high. The floor of the outlet was made of concrete, on which rest the walls which are 1 foot thick, and these are covered with flagging. Both the top and sides were covered with a layer of concrete before the earth was packed around them. Walls 3 feet thick were built at both the upper and lower ends to support the earth filling. The gate well is of masonry and is 32 feet deep, and 4 by 4 feet inside, with walls 2 feet thick resting on a concrete foundation 3 feet thick. The gate is of wood, faced with iron plates, and slides in a wooden frame at the outer opening of the well. The wooden gate stem terminates in an iron rod working in a stationary nut. The stem is braced by an iron collar. A concrete collar to prevent water following along the outside is placed around the conduit 19 feet below the well. A peculiar feature is a brick drain from the collar to the lower end of the outlet, the purpose of which is to readily carry away any water that may find its way past the collar and keep it from creeping farther through the earth. The drain naturally collects the water since it offers the greatest freedom of flow. It is placed along one upper corner of the conduit and is about 3 by 4 inches in cross section.

In the fall of 1902 the southeast bank of the reservoir was riprapped with stone in places for an aggregate distance of one-half mile as a protection not to the reservoir but to the canal just above it.

The reservoir has an area of 226 acres, and 30 feet of water may be drawn off. Its capacity is 4,726 acre-feet. The total cost was $12,000, or $2.54 per acre-foot of capacity.

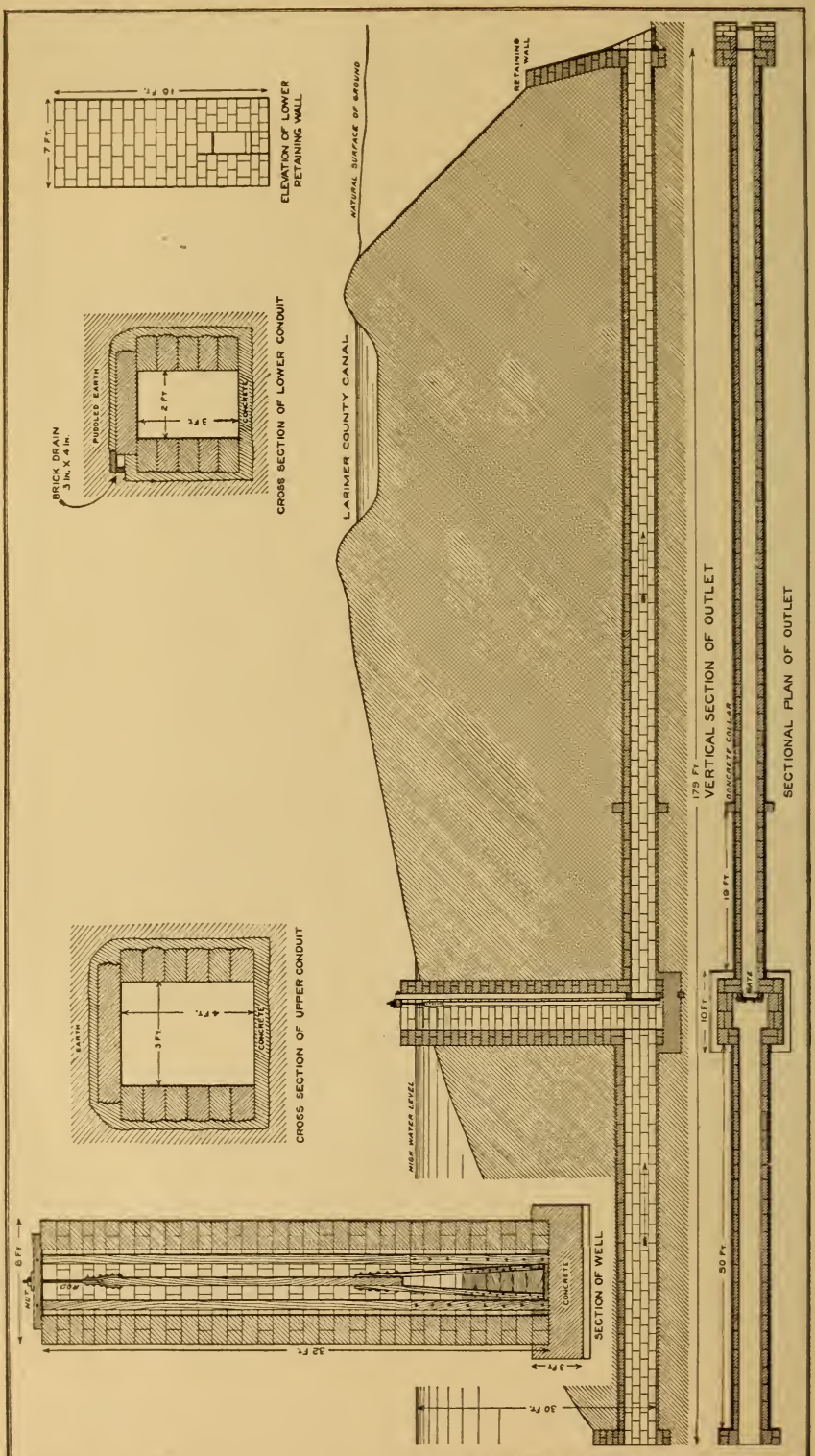


FIG. 3.—Design of outlet of Rocky Ridge Reservoir.

RESERVOIRS NOS. 2 AND 3.

Reservoir No. 1 discharges directly into No. 2 south of it. No. 2 has no regulating gate at its outlet, but is simply connected with No. 3 to the south of it by a cut, and so Nos. 2 and 3 are practically one reservoir. No dams were necessary to form these basins. The outlet at the south side of No. 3, which was placed in a cut, consists of a stone conduit with a wooden gate working in a masonry well near the middle and is quite similar to that of No. 4, to be described later.

The area of these two basins is 128 acres, and the water is 11 feet deep at the outlet when they are full. Their capacity is 1,026 acre-feet.

RESERVOIR NO. 4.

The only embankment necessary at Reservoir No. 4 was one about 5 feet high over the outlet. This was given a slope of 4 to 1 on the inside and 1½ to 1 on the outside. The inner face is riprapped. The outlet works are similar in many respects to those of No. 1. There is a stone conduit 96 feet long with walls 5 feet high at both ends. The gate well, 4 by 4 feet inside and 21 feet deep, is nearly at the middle of the outlet. Above the well the conduit is 2 feet wide by 4 feet high, but below the well the height is reduced to 3 feet. Its walls are 1 foot thick, and the floor is formed by laying flagging on a foundation of concrete. Two concrete collars were placed around the outlet below the well and the earth filled in on top of the outlet was puddled with water.

The gate is of wood faced with iron plates and the wooden stem, 8 by 8 inches, is braced by one guide. The stem terminates in an iron rod carrying a nut which is turned by a wrench when the gate is moved.

The basin is 83 acres in area and 19 feet deep over the outlet, and holds 996 acre-feet.

LONG POND RESERVOIR.

Long Pond is Reservoir No. 5 in the system, the name being given because of its oblong basin extending northwest and southeast. No dam was required, the basin being natural and containing some water before it was used for storage purposes.

A cut 35 feet deep, in which to build the outlet, was made through the small ridge on the lower side of the basin. The outlet is a stone conduit 3 feet wide and 4 feet high. The bottom was made of 6 inches of concrete and the masonry walls on each side are 18 inches thick at the bottom and 1 foot at the top, the batter being on the outside. The top of the outlet is made of flagging 6 inches thick. At both the upper and lower ends a transverse wall was constructed to support the earth filling, the lower one having wings supporting the earth at either side of the open cut. This cut extends for several hundred feet below.

Fig. 3.—Design of outlet of Rocky Ridge Reservoir.

The gate well is near the upper end of the outlet. It is 3 by 4 feet inside and has walls 2 feet thick. The wooden gate is faced with iron plates and slides in a wooden frame. At the top of the gate stem a nut turned by a wrench serves as a lifting apparatus.

The reservoir is 230 acres in area and 29½ feet of water may be drawn off. It holds 3,922 acre-feet. The reservoir cost $12,000, or $3.06 per acre-foot of its capacity.

LINDENMEIER LAKE.

Lindenmeier Lake was originally a natural lake, and to utilize it as a reservoir it was only necessary to make a cut to drain the water off. This was made at the southeast corner and was used for several years with a wooden head gate in the open cut to regulate the discharge. In the fall of 1902 outlet works similar to those of the other reservoirs in the lower system were installed. The stone outlet is 3 feet wide and 4 feet high above the gate well, while below its height is only 3 feet. The floor is made of 4-inch and the top of 10-inch flagging. The well is 3½ by 4 feet inside, and 10 feet deep, and its walls are 2 feet thick. The well rests on a foundation of 20 inches of concrete, and the conduit on 6 inches of the same material. The length of the outlet above the well is 16½ feet and below 25 feet. Walls for supporting the earth filling were constructed at both ends. One concrete collar is placed around the outlet below the well. The gate and gate stem are wooden, and the manner of operating is similar to that of the gates previously described.

Lindenmeier Lake is 106 acres in area and is filled to a depth of 8 feet over the outlet. Its capacity is 716 acre-feet.

CURTIS LAKE.

Curtis Lake, the latest acquisition of the Water Supply and Storage Company, was a natural lake. It has no embankment and the outlet is of the same pattern as that of Lindenmeier Lake, consisting of a stone conduit rectangular in cross section and a wooden gate faced with iron plates and operated in a masonry well.

The area of Curtis Lake is 113 acres, the depth 9 feet, and the capacity 778 acre-feet.

CHAMBERS LAKE.

Chambers Lake is one of the oldest reservoirs on Cache la Poudre River and until recently was unique as the only mountain reservoir in this section of Colorado and the only one where a dam was constructed across the channel of a natural stream. Its location is at that point where Fall River, Joe Wright Creek, and Trap Creek join to form the Middle Fork of Cache la Poudre River. This point is 35 miles west in a straight line and about 70 miles following the

WASTEWAY AND OUTLET GATES OF CHAMBERS LAKE, EAST END OF EMBANKMENT AT EXTREME LEFT.

course of the river, from the head gate of the Larimer County Canal through which the water stored in Chambers Lake is used. The elevation of the reservoir is about 9,300 feet.

In 1885 the Larimer County Ditch Company, which was incorporated later as the Water Supply and Storage Company, constructed a dam 17 feet high at the outlet of Chambers Lake, making its capacity 134,176,800 cubic feet. This dam was made by building up a crib of logs to a height of about 8 feet, filling it in with gravel, and giving the embankment the usual steep outside and flat inside slopes above the top of the crib. The outlet through the dam was made of wood and the gate placed at the upper end was operated from a platform built out in the reservoir from the dam.

The waste way was a wooden chute set in a gravel bank at the north end of the dam. In June, 1891, the water cut through the gravel around the structure and the utility of the reservoir as well as of the waste way was destroyed. The dam itself, while not as carefully designed and constructed as is desirable in a dam to check the flow of a stream subject to floods, has stood until the present time. The flood in the river due to the accident destroyed some property along the banks and suits were brought against the company, which paid for all damages.

The year following the accident a new waste way was constructed in the same place; it is a well-made timber structure over which the surplus water flows. (Pl. IV.) As it was built high enough to impound water to a depth of only 11 feet the original dam is now much higher than is necessary. The gravel on the lower side of the dam around the lower end of the outlet caved in and the company, fearing that the dam would eventually go out, abandoned and closed this outlet and made a new one at the south end of the new waste way. This is similar to the wooden head gates ordinarily used at the heads of the canals. There are five gates each raised by a screw.

The company utilizes Lost Lake, Trap Lake, and Laramie Lake, which are just north of Chambers Lake. Small dams have been constructed and channels cut connecting the basins with Chambers Lake.

The area of Chambers Lake is 180 acres, and its capacity is 1,259 acre-feet.

OPERATION OF THE SYSTEM.

The appropriation of the Larimer County Canal of 469.8 cubic feet per second was made in 1881, and it is No. 100 in order of priority. At that time this appropriation was the latest of the large canals on the river, that of the North Poudre Canal having been made in 1880, and so it was only at a very high stage of water in the river that the canal was entitled to divert any water. It was, therefore, necessary that the company provide for an additional supply in some manner. Realizing the condition, the company has been ever active and at present

it has one of the most successful and substantial irrigation systems in this section of Colorado. Beginning with Chambers Lake the storage system was gradually developed, the two large reservoirs, Rocky Ridge and Long Pond, being improved in 1892.

Decreed priorities have been granted by the court for the reservoirs as follows:

Nos. 2, 3, and 4, dating from April 25, 1881, for a depth of 6 feet, or 880,064,500 cubic feet; Chambers Lake, from July 12, 1882, 134,176,800 cubic feet, and Nos. 1 and 5, from 1893, 381,710,020 cubic feet. The latter was at first given with that of Nos. 2, 3, and 4, but later it was postponed and made junior to that of the Windsor Reservoir. The rights of Lindenmeier and Curtis lakes have not been decreed. Nos. 2, 3, and 4 and Chambers Lake have the earliest priorities given to any reservoirs on the river except Warren Lake Reservoir which was given a decreed appropriation along with the ditches when the rights to the stream were adjudicated. Reservoirs Nos. 1 and 5 can not be filled until the Windsor and Cache la Poudre reservoirs are filled.

The company has not only been progressive in the construction of storage works, but has provided for a supply of water to fill them in rather an unusual manner. Their methods, however, are now followed by a number of the other companies. In 1893 they constructed, at a cost of $90,000, the Laramie River or Sky Line Ditch, which collects its supply from the head waters of the Laramie River and carries it over the divide to Chambers Lake. This ditch, after leaving the west branch of the Laramie River, runs 1 mile northeast, at which point it tunnels through a rocky point and turns to the south, following along the valley of another branch of the Laramie River until it crosses the divide and enters Chambers Lake. Its total length is less than 5 miles. In its course the ditch crosses many small creeks of the Laramie drainage and catches the flow of each. To carry all of this the capacity of the ditch had to be increased from 200 cubic feet per second at the head to 350 cubic feet per second at the lower end. The water carried to Chambers Lake is either stored there or run down the Cache la Poudre River to the other reservoirs, or used directly through the Larimer County Canal in the irrigating season. The construction of the ditch was in many places quite difficult, cuts having to be made through solid rock and on very steep slopes. The company is allowed by a decree of the court to divert and carry over the divide through the Laramie River Ditch, for storage in their reservoirs, 500,000,000 cubic feet of water annually. In the season of 1902 the ditch was first used on May 15, when it carried 55 cubic feet per second, and on May 28 the discharge had increased to 130 cubic feet per second. The average for June was 150, for July 90, for August 50, and for September 20 cubic feet per second. This is an

average of about 89 cubic feet per second for the four and a half months and gives a total of about 950,000,000 cubic feet, or more than enough to fill all the reservoirs of the company one and a half times.

The Cameron Pass Ditch is another ditch in the mountains owned by the company. It diverts water from Michigan Creek, a tributary of the Laramie River, and carries it over the divide through Cameron Pass into Joe Wright Creek, a tributary of Chambers Lake. This ditch has two decreed priorities, one dated 1882, for 10 cubic feet per second, and another dated 1898, for 18 cubic feet per second more. In 1902 the branch of Michigan Creek from which the ditch is taken was very low. Its maximum flow was 7 cubic feet per second on June 8 and on June 30 it was dry, having carried water for only thirty days.

The company has also constructed that part of the Grand River Ditch known as the South Ditch, and by the fall of 1903 expects to have completed the lower 7 miles of the North Ditch. The two ditches run along the western and southern slopes of the Continental Divide and carry water from streams tributary to the Grand River over the divide to the Cache la Poudre. Numerous streams which are crossed by the ditches reinforce the flow. The two ditches meet and discharge their waters through South Poudre Pass at the head waters of what is commonly called the Big South Poudre, a stream which joins the Middle Fork of the Cache la Poudre several miles below Chambers Lake, but it is distinct from the South Fork of Cache la Poudre River. The North Ditch will be 12 miles long when completed, and it is estimated that the first 7 miles will furnish as much water as the Laramie River Ditch. It is not expected that any trouble will arise over the diversions from the Grand River, as its water supply is probably still much in excess of the amount that can be used from it in its own valley.

The Water Supply and Storage Company purchased 3¼ shares of the Dry Creek or Jackson Ditch from the Larimer and Weld Reservoir Company, which had secured a right to store the water supplied on them at all seasons by a decision of the supreme court in a case between the Cache la Poudre Irrigating Company and the Dry Creek Ditch Company and others. In this case the storage of surplus water on the excessive decrees of an old ditch is allowed by the court even during the irrigation season. The water secured by these mountain ditches from other drainage basins is stored throughout the irrigation season.

All the reservoirs of the Water Supply and Storage Company except Chambers Lake are below the Larimer County Canal, which serves as their inlet from the river. Its capacity is 463 cubic feet per second. Reservoir No. 1 receives water direct from the canal, and the basins below receive their supply from No. 1. Curtis Lake is filled directly from the canal through its own inlet.

The stock of the Water Supply and Storage Company is composed of

600 shares, each representing one water right, or one six-hundredth part of the water in the reservoirs and the Larimer County Canal. Each right is entitled to 22.37 acre-feet in the reservoirs, and in 1902 was worth $2,250. Seven years ago they were worth only $500 each. Chambers Lake cost $60,052, or $47.68 per acre-foot, while the remainder of the system cost only $50,000, or $4.11 per acre-foot. The latter low figure is due to the circumstance that the reservoirs required no artificial dams of any consequence. The average cost of all the reservoirs per acre-foot of holding capacity is $8.19. The annual cost of maintenance of the company's property, including the canal, is $1,000.

From the location of the reservoirs of the Water Supply and Storage Company it is necessary that the water, with the exception of that of Chambers Lake, be used by exchange. The outlet of Lindenmeier Lake flows into Dry Creek and enters the river above the head gates of Cache la Poudre No. 2 and Cache la Poudre No. 3 canals. The outlet of No. 5 into Lindenmeier Lake flumes over the Larimer and Weld Canal, and the water in No. 5 and in those of the system north of it can be turned into the canal, or, together with that in Lindenmeir Lake, can be run into the river. Curtis Lake discharges into Dry Creek. The exchange is usually made by running the stored water through the Larimer and Weld Canal, the same amount being given to the Cache la Poudre No. 2 and Cache la Poudre No. 3 canals from the Windsor Reservoir, and, finally, a like amount is taken into the Larimer County Canal from the river. Since the lower canals have rights senior to those of the Larimer County Canal, they are always entitled to enough water to make the exchange. The first exchange of water in the valley was made in 1892, when Reservoir No. 5 was emptied into the Larimer and Weld Canal and a like amount from its share in the water of the river given to the Larimer County Canal.

The company has used its reservoirs to maintain a constant flow in its canal, which further complicates the distribution. If the river is high enough to entitle the Larimer Canal Company to water exceeding the amount specified to be constant in the canal, the excess is turned into the reservoirs. If, when the river recedes, the share of the canal falls below this amount, water is turned out of the reservoirs to the canals farther down the river, and they, having old rights, permit the company to divert water into its canal to still maintain the constant flow. Owing to the late priority of the rights of the canal the stored water must be used throughout the entire season, although most of it is used for late irrigation from about August 1 to 10. Wheat and the first two crops of alfalfa are irrigated in the spring, and potatoes, sugar beets, and the third crop of alfalfa in the fall. In 1902 Chambers Lake was emptied at the rate of 100 cubic feet per second, commencing August 23. In this year practically no water was secured on the decree

of the canal itself, although some was obtained by the use of rights in the Pioneer Ditch.

In the distribution the plan formerly was to run water through the whole canal all the time, but in 1902 alternate runs of four days each were made to two divisions, the upper and the lower. This system allows a greater amount of water to be run; the distance also being shorter when supplying the upper division; the company has found this to be an economical method, and has decided to continue it. The company uses a weir in each lateral, and has also a large one in the outlet ditch from Lindenmeier Lake where water is measured in exchanging. The gate used at the heads of the laterals from the Larimer County Canal is the Powell head gate. This is an iron gate covering an iron tube extending through the canal bank and operated by an iron rod extending to the top of the bank. The gate is not vertical, but slopes with the bank of the canal.

During 1902 the Water Supply and Storage Company sold from its reservoirs 55,000,000 cubic feet of water to the Larimer & Weld Reservoir Company and 35,000,000 cubic feet to Mr. B. H. Eaton, the price being $100 per million cubic feet in each case.

NORTH POUDRE IRRIGATION COMPANY'S SYSTEM.

The North Poudre Irrigation Company was formerly known as the North Poudre Land, Canal, and Reservoir Company. The company owns the North Poudre Canal, which heads in the canyon of the North Fork of the Cache la Poudre River. It is the highest canal in the valley and the only large one not having its head gate on the main river. This company has also recently acquired part ownership in the Poudre Valley Canal, through which a part of its reservoirs may be filled. It is unfortunate for the canal that the North Fork is considered a part of the main river in the adjudication of rights, for, the canal having the latest right among the large canals, it is often necessary that its head gates be closed and the flow of the North Fork allowed to pass by to reinforce the main river for filling the canals having older rights. On the other hand, the North Poudre Canal, from its location, profits nothing by a flood in the main river. The decree of the North Poudre Canal was granted by the court in 1880 and that of the Larimer County Canal not until the following year, but in 1893 the court decided that the former should be junior to the latter on the grounds that the North Poudre Company had not used proper diligence in constructing its canal.

The construction of the reservoirs of the company has therefore come from necessity and has been stimulated by a realization of the value of reservoirs as a part of an irrigation system. The system has been developed gradually since 1883, and at present the company owns a greater number of reservoirs with a greater total storage capacity

than any company in this section of Colorado. The company believes that with the completion of the Fossil Creek Reservoir and the Poudre Valley Canal the lateness of its right and all other difficulties have been overcome.

RESERVOIR NO. 1.

Reservoir No. 1 was constructed in 1883. Three embankments were necessary in its construction, two each 100 feet long and one 200 feet long, the greatest height of any of them being 10 feet. They are 14 feet wide on top, and the outside and inside slopes are respectively 3 to 1 and 2 to 1. All the dams are riprapped.

The outlet is through two wrought-iron pipes 10 inches in diameter laid in a cut under one of the dams and fitted with valves at the upper end. The valves are operated from the top of a wooden bridge or platform built out from the top of the dam.

The area of the reservoir is 80 acres, the depth 14 feet, and the capacity 674 acre-feet. It cost $3,000, or $4.45 per acre-foot.

RESERVOIR NO. 2.

Reservoir No. 2 was commenced in 1884, but was not completed until 1891. The dam is 2,000 feet long and its top is 35 feet above

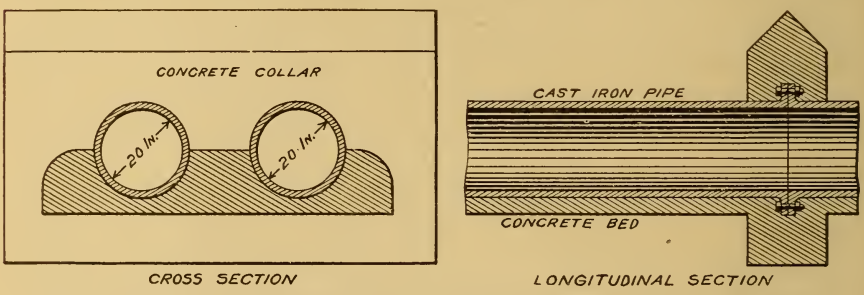


FIG. 4.—Cast-iron pipe outlet of North Poudre Reservoir No. 2, with concrete bed and collars.

the outlet. The outside slope is 2 to 1 and the inside slope 4 to 1. The dam is 15 feet wide on top and its inner slope is well riprapped.

The outlet consists of two lines of 20-inch cast-iron pipe in sections 12 feet long, flanged and bolted together. The pipes rest on concrete and a collar surrounds each joint (fig. 4). At each end the pipes protrude through a heavy masonry wall constructed on a base of concrete. The Chapman valves controlling the discharge are at the lower end of the pipe, a plan, however, which would not have been permissible if the outlet had been of stone. One advantage of this plan is that the gate is always conveniently approached in case anything interferes with its operation.

The area of the reservoir is 300 acres and its capacity is 5,000 acre-feet. Its cost was approximately $7,500, or $1.50 per acre-foot.

RESERVOIR NO. 3.

Reservoir No. 3 was commenced in 1884, but was not completed until 1888. There is one embankment, which is 500 feet long, with inside and outside slopes of 1½ to 1 and 3 to 1, respectively. The upper face of the dam is riprapped.

The outlet is a 20-inch cast-iron pipe, which is 31 feet below the top of the dam. There are two lines of pipe of 12-foot sections bolted together and laid in a bed of concrete 18 inches thick and 6 feet wide. Masonry walls with wings were constructed at both ends, and a water-works valve placed at the upper end regulates the discharge. The valve stem extends to a wooden platform built out from the top of the dam.

The reservoir is 155 acres in area and 26 feet of water may be drawn from it. Its capacity is 2,550 acre-feet. It cost $5,000, which gives only $1.96 per acre-foot of its holding capacity.

RESERVOIR NO. 4.

Reservoir No. 4 was developed in 1890 by building a dam 500 feet long. The dam is 15 feet wide on top, is riprapped with stone, and the slopes are 2 to 1 on the outside and 4 to 1 on the inside.

The outlet is a cast-iron pipe of 20 inches inside diameter, the joints being bolted together. The pipe rests on a foundation of concrete and the joints are surrounded by concrete collars. At each end the pipe is surrounded by transverse masonry walls. The gate is a Chapman valve placed at the lower end, where the water discharged falls on an apron of flagging.

The water is 15 feet deep over the outlet and the area of the high-water surface is 147 acres. The reservoir holds 1,074 acre-feet. The cost of construction was $5,000, or $4.66 per acre-foot of its capacity.

RESERVOIR NO. 5.

The basin of Reservoir No. 5, which is entirely natural, is one-half mile wide and over 1 mile in length. About 1884 a cut 22 feet deep was made through the rim of the basin at the southeast end to drain it. No outlet works were installed until 1892, when a temporary wooden headgate capable of impounding 10 feet of water was put in. In this condition the reservoir has been used since 1895, except during the years 1898 and 1899. When finally perfected according to the plans of the company, the outlet will consist of large vitrified pipes with gates operated in a masonry well at the middle of the outlet, the whole to be placed in the open cut, which will then be refilled.

When complete the reservoir will hold 20 feet of water, the surface area of which will be 495 acres. Its capacity will be 5,740 acre-feet.

Up to the present time the cost has been approximately $2,000, and when complete the cost will be very small considering the amount it will store. With an estimated total cost of $10,000 the cost per acre-foot would be only $1.74.

RESERVOIR NO. 6.

This is one of the largest reservoirs of the North Poudre Company's system. The basin is partly natural and is 2 miles in length from northeast to southwest, with an average width of one-third mile.

The outlet works were placed in a cut through the rim of the basin at the southeast end. The conduit is 3 feet wide and 4 feet high. Its floor is 6 inches of concrete 6 feet wide, on which rest the side walls, 18 inches thick at the bottom and 1 foot thick at the top, the batter being on the outside. Flagging 6 inches thick supports the earth filled in on top. The conduit is 100 feet long, and walls 17 feet long, 9 feet high, and 2 feet thick are built around both ends. Beyond the walls aprons 25 feet long were made by laying 2 by 4-inch lumber flatwise and lengthwise. The masonry gate well is 40 feet from the upper end, and is 4 by 4 feet inside and has walls 2 feet thick. When the outlet was constructed in 1899 the well was only 18 feet high, but in the fall of 1901 it was built up to 30 feet in height. At the same time the original oak gate was replaced by an iron gate, which is moved by means of a nut turned by a lever.

When complete, the reservoir will have an embankment at the outlet which will impound water to a height of 12 feet above the natural surface of the lake. This will require about 50,000 cubic yards of earth, but the gate well is already completed to the full height. At present the company is arranging for the completion of the reservoir.

The area of the reservoir is 572 acres, and nearly 30 feet of water can be drawn off. Its capacity, when complete, will be 11,478 acre-feet. The cost of construction to the present time is $3,000, and, when complete, it is estimated that it will be $13,000, which will make the cost per acre-foot $1.13.

RESERVOIRS NOS. 7 AND 8.

The sites for these reservoirs have been acquired by the company, but they have not been improved. The basins are natural and it is only necessary to make cuts to drain the water off. They will be practically one reservoir, the water in No. 7 being run into No. 8 through an open cut, and there will be only one discharge gate, located at the south side of No. 8.

No. 7 is 20 feet deep and 240 acres in area, and has a capacity of 2,399 acre-feet; No. 8 is 40 feet deep and has an area of 357 acres, and a capacity of 8,400 acre-feet. No. 7 will hold more if furnished with

a head gate, and the capacity of No. 8 may be increased by connecting a small basin on the southeast by an open cut. The estimated cost for developing the two basins is placed by the company at $10,000, which will give 93 cents as the cost per acre-foot.

RESERVOIR NO. 9.

An outlet cut has been made from this basin, but to complete the company's plans it still requires outlet works and a small embankment for impounding a greater depth of water. The area is 100 acres, and its depth 30 feet. The basin will hold 1,722 acre-feet.

RESERVOIR NO. 11.

Reservoir No. 11 is a site just below the North Poudre Canal and west of Box Elder Creek, consisting of what is commonly called Stuchell Lake. It is small in capacity.

COAL CREEK RESERVOIRS.

These reservoirs were originally two natural basins known as Clark's Lakes, which were developed in the summer of 1902 as reservoirs Nos. 12 and 13 of the system. The two basins are connected, a cut being made from No. 13, in which outlet works were installed.

The combined capacity of the reservoirs is 4,477 acre-feet, and their area 175 acres. The cost was $6,000, which includes the expense of extending the North Poudre Canal and of constructing an inlet from Coal Creek. The cost per acre-foot was $1.34.

RESERVOIR NO. 15.

On account of the fact that so many of the company's reservoirs can in the future be filled from the main river through the Poudre Valley Canal the company now considers it feasible to construct a new reservoir to be numbered 15, above the North Poudre Canal and about 3 miles north of No. 1. A site has here been found which is above all the land under the canal. It is proposed to use several miles of the North Poudre Canal as originally constructed in running the water from the North Fork in a northeasterly direction to a branch of Dry Creek. After this stream reaches the plains a ditch 1½ miles long can be constructed to convey the water to the site. An outlet is needed to turn the water from the basin into the North Poudre Canal.

The area of the site is 296 acres; the capacity claimed is 615 acre-feet, and the total estimated cost is $22,000.

FOSSIL CREEK RESERVOIR.

The Fossil Creek Reservoir was constructed in the spring of 1902 and was partly filled and used during the same year. It is the only large reservoir in the valley south of the Cache la Poudre River, and

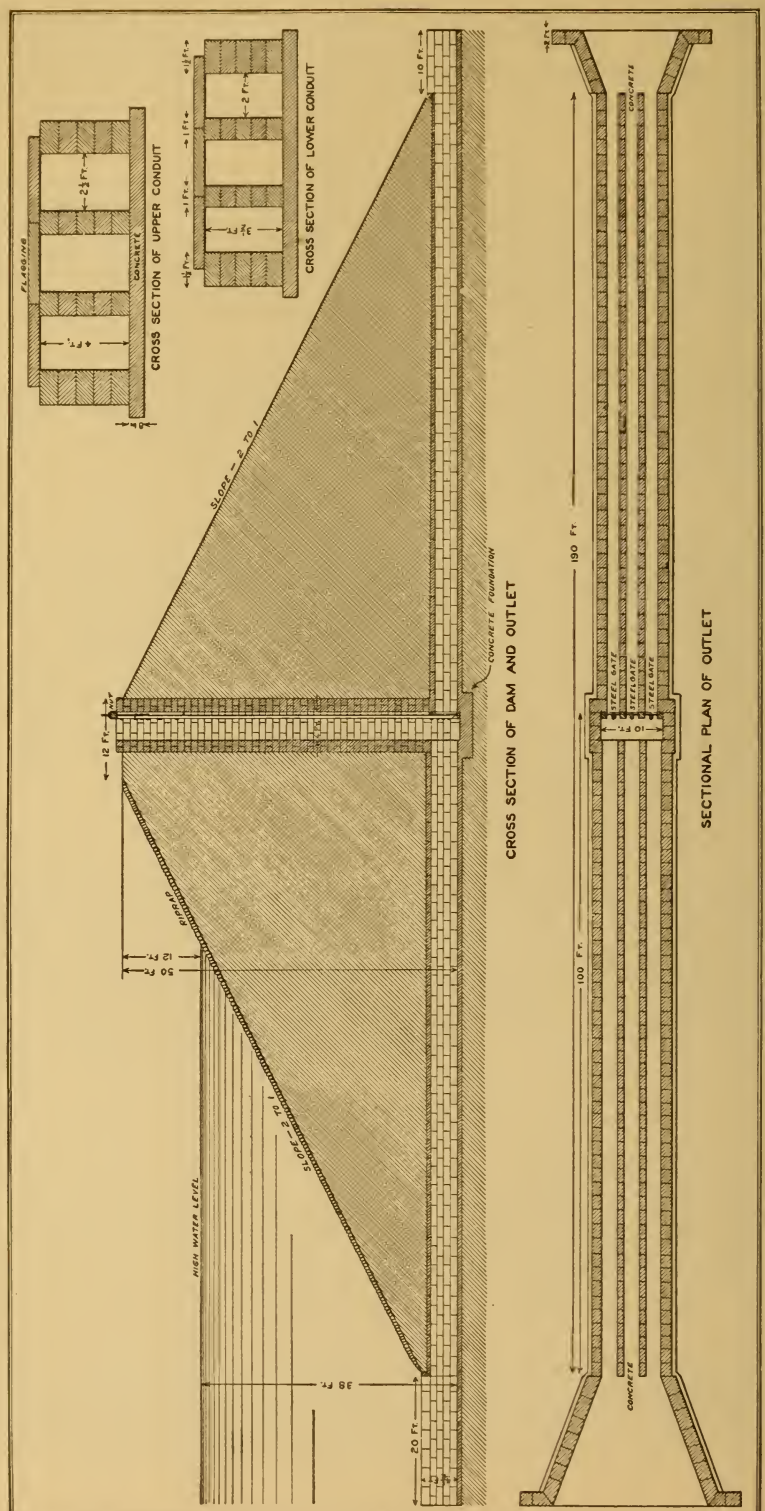


Fig. 5.—Design of dam and outlet of Fossil Creek Reservoir.

is also distinctive as being completely isolated from the rest of the North Poudre Irrigation Company's system. It is located in the bed of Fossil Creek, a short distance above its junction with the river, the dam being at a point where the shallow valley of the creek was narrow compared with the portion above. While the dam could probably not have been placed to make the plan any more feasible, it was an enormous and expensive undertaking.

The embankment as constructed is one-half mile long, and varies in several respects from the usual form employed in the valley (fig. 5). The slopes on both sides are 2 to 1, while ordinarily an inside slope is from 3 to 1 to 5 to 1. Water has a tendency to make the inner slope of an embankment flat, and the company, realizing this, has covered the entire inner slope of the dam with a riprapping superior in character to any other in the valley. The large rectangular stones used were placed by hand, and give the riprapping the appearance of rubble masonry (Pl. V). The width of the top of the dam is 12 feet, which, considered absolutely, is small for the height of 50 feet, but since the top of the dam is 12 feet above high-water mark this is not a point that can be criticised. If without changing the base and slopes of the dam this additional height above the water surface were only 6 feet, a height ordinarily considered sufficient, or supposing that the upper 6 feet were cut off, then the width of the top would be 36 feet. The thickness at the high-water mark is 60 feet.

The outlet is of stone, and is through the embankment below the point of its greatest height. The well in which the gates operate is at the middle of the embankment, is 4 by 10 feet inside, and has walls 2 feet thick. There are three conduits, each $2\frac{1}{2}$ feet wide by 4 feet high above the gates and 2 feet wide by $3\frac{1}{2}$ feet high below the gates. This difference of size between the upper and lower ends of the conduits is intended to increase the discharge, and is a feature of a number of the reservoirs of the Water Supply and Storage Company. The foundation and floor of the outlet is 8 inches of concrete. The two outer walls are $1\frac{1}{2}$ feet thick, while the two forming partitions between the conduits are 1 foot thick. The thickness of the flagging on top is increased from 4 inches at the end of the outlet, where there is very little pressure, to 10 inches at the middle, where the great weight of the embankment is supported. The walls of the gate well above the openings into the conduits are supported by six capstones, each 1 by 1 by $3\frac{1}{2}$ feet. The concrete foundation is extended to form aprons 20 feet above the outlet and 10 feet below it, and on these rest the wing walls, $4\frac{1}{2}$ feet high and 2 feet thick. The three steel gates have wooden stems, and in moving them power is applied by means of screws at the top of the well or gate chamber.

The following is the amount of material used in constructing the outlet: 78 cubic yards of concrete, 272 cubic yards of masonry, and

1,666 square feet of flagging varying in thickness. The riprapping of the dam required 7,174 cubic yards of stone, which was hauled from quarries in the foothills 15 miles distant.

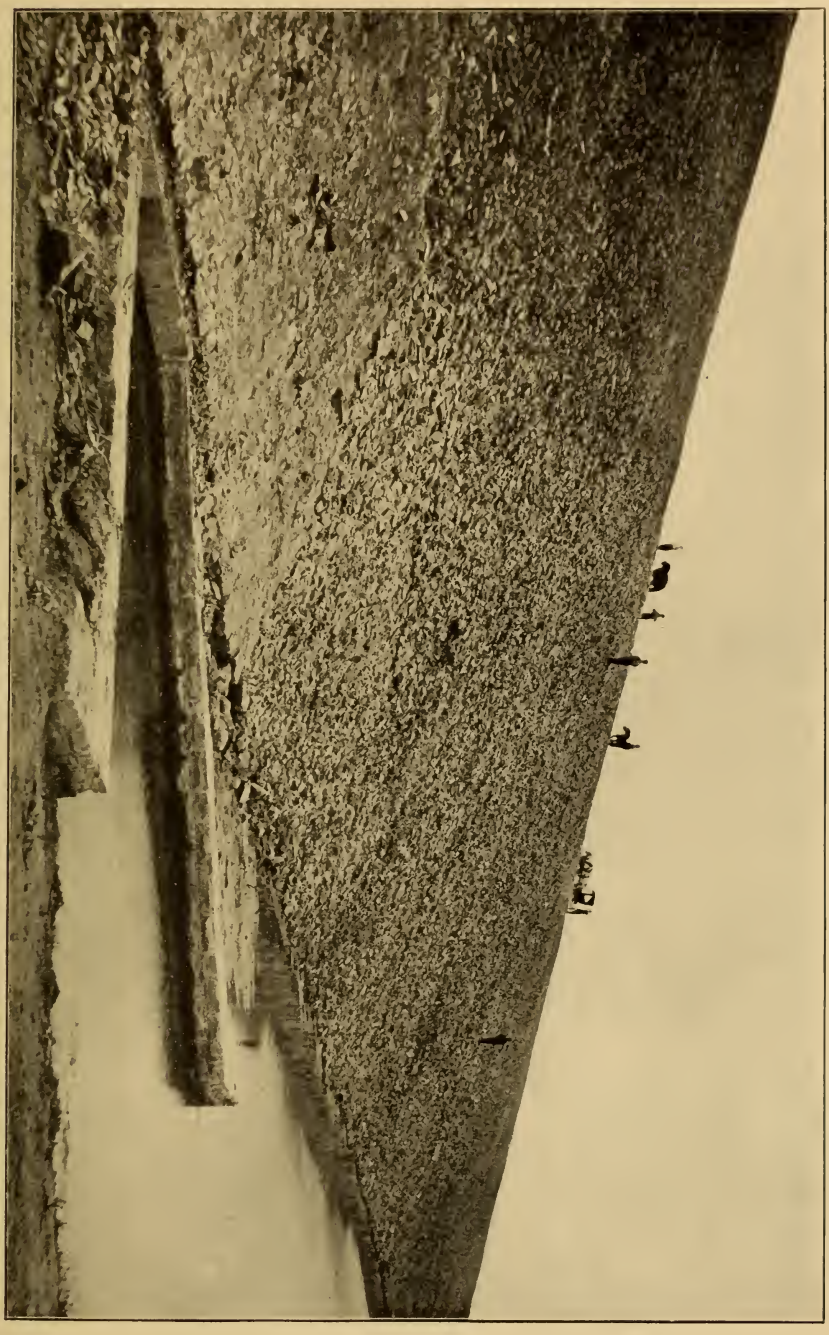
A distinctive feature of the reservoir is its waste way 600 feet wide. It is over a natural hill on the southeast side of the basin and at a distance of one-fourth mile or more from the dam. Fossil Creek is subject to floods, and since the dam crosses the channel of the stream it is necessary that the waste way be large enough to carry all surplus water and keep the water level from exceeding the limit of safety.

The reservoir is 705 acres in area and holds 11,478 acre-feet. Its cost, including the inlet and outlet ditches, was $160,000, or $13.94 per acre-foot, the latter figure being exceeded only by that for Chambers Lake among the reservoirs discussed. The dam alone cost $80,000.

The inlet ditch has a capacity of 400 cubic feet per second and runs south from the Cache la Poudre River a distance of about 4½ miles. In running the grade line of the ditch it was found that the head in the river would have to be a short distance above the mouth of Box Elder Creek, which enters the river from the north. Most of the reservoirs of the company on the north side of the river can be emptied into Box Elder Creek making it serve as an outlet to the river. Therefore, that the Fossil Creek reservoir might profit by floods in Box Elder Creek or figure in exchanges with reservoirs on the north side, it was necessary for the company to change the course of Box Elder Creek near its mouth. This was done by constructing a ditch which turns the waters of the creek into the river just above the head of the reservoir inlet.

There are many differences of opinion regarding the amount of water available for filling the Fossil Creek Reservoir. The company proposes to fill it twice each year—once during the winter for early irrigation and then again during the spring floods, which usually come in June, for the late irrigation of vegetables.

Beside the supply received from Cache la Poudre River and Box Elder Creek through the inlet ditch, the floods in Fossil Creek are available for filling the reservoir. This creek, although nearly dry a part of the year, at times has contained a great amount of water flowing with great velocity to Cache la Poudre River, and the mouth of Fossil Creek being not only below the head of any reservoir inlet ditch but below that of any of the larger canals save one, the Cache la Poudre No. 3, some of the water would be lost to the irrigators in this valley. These floods soon recede, but the creek flowing directly into the basin itself, there is, in this case, no limit to the rate at which water can be stored as is the case with some, on account of the limited capacity of their inlets. A storm occurred June 13, 1901, flooding Fossil Creek, and it is estimated by those who saw this flood that the water rushing past the place where the dam is now constructed



DAM AT UPPER END OF OUTLET, FOSSIL CREEK RESERVOIR.

was 6,000 cubic feet per second, a discharge which would fill the reservoir in twenty-three hours. These estimates are, doubtless, greatly exaggerated, but there being no measurements on which to base a reliable statement, it remains to be seen just what Fossil Creek will do toward filling the reservoir. On March 3, 1903, the reservoir had been filled to within 20 inches of the high-water line and the head gate of the inlet ditch was then closed, as surface drainage was expected to complete the filling even without the June floods.

After completing the reservoir in 1902 some water was secured through its inlet, but it is claimed that this was mainly seepage water which should not have been stored. However, it is probable that nearly all the inlets in the valley are benefited by seepage water entering them from irrigated lands above. The company's right to the waters of Fossil Creek when storage is allowable is conceded, but since the reservoir has no decree and its claim to water from the river is one of the latest, it will probably not be entitled to water from the river except during flood times. It is the intention of the company to fill the reservoir twice each year, if possible—once from Fossil Creek during the winter and a second time from the river through the inlet ditch. This would be the most economical use of the water and should be established on a legal basis. But if any reservoirs following it in order of priority should be deprived of water for storage it is probable that objections will be made, for water is becoming so valuable that every possible means of increasing the supply is seized upon.

The company claims the right next after the Cache la Poudre Reservoir to use the 60 cubic feet per second of water returned to the river by the flouring mill at Fort Collins, because it is the first ready to receive it; and if any of this is not used by the latter during the time for storing, the Fossil Creek Reservoir will probably get it, as it is the only other one with an inlet placed so as to receive it. It is said that an inlet ditch may be constructed from a point in the river below the tail race of the mill to the Windsor Reservoir, but the early priority of this reservoir would certainly not be sufficient reason to entitle it to precede the other two which already have their inlets constructed.

Fossil Creek itself joins the river below the head of the Cache la Poudre No. 2, but the outlet ditch from the reservoir has less fall and discharges into the river just above the head gate of the canal, so that the water may be used through either this canal or the Cache la Poudre Canal No. 3.

There are 300 of the first or preferred water rights in the reservoir, each corresponding to 80 acres. After the completion of the reservoir in 1902, 20,000,000 cubic feet of water was stored, and irrigators under the Cache la Poudre Canal No. 2 purchased 150 of the rights for $300

each, but it is not the intention to sell any more. An assessment of $4 per annum is made on each right for maintenance. When it is considered that the common price of 1,000,000 cubic feet of water in the valley during 1902 was $100 and in one case at least it was $150, it is surprising that these rights entitling the owners to 1,000,000 cubic feet annually, for all time, could be purchased for so low a price as $300. The reason for this was the immediate need of funds to meet the expenses of the company, it having invested large amounts in new works which had not yet yielded returns.

OPERATION OF THE SYSTEM.

None of the North Poudre Company's reservoirs on the north side of the river has been decreed a certain amount based on its capacity, but the decree given the North Poudre Land, Canal and Reservoir Company entitled it to 315 cubic feet per second from the North Fork of the Cache la Poudre for the canal and for the filling of the first ten reservoirs. The date of this priority is February 1, 1880, but it is practically of little value. Testimony is now being taken for the adjudication of reservoir rights in the Cache la Poudre Valley, and it is expected that all of the company's reservoirs already constructed will be decreed priorities. Nos. 1 and 3 will doubtless have very early ones.

All of the company's reservoirs on the north side may be filled through its canal. Reservoirs Nos. 1, 2, 3, 4, 5, 12, and 13 are each above at least some of the land under the canal, while Nos. 6, 7, 8, and 9 must be made to serve the needs of the company by exchange. No. 1 has its own inlet ditch from the canal 2 miles north of it. The water may be used directly through the inlet ditch or may be run into Dry Creek and to the river for exchange purposes. Six of the reservoirs form a chain lying in the country between Dry and Box Elder creeks on the east and west and between the North Poudre and Larimer County canals on the north and south. An inlet ditch from the North Poudre Canal enters Reservoir No. 2 at the north, and the others are connected with No. 2. The main outlet at No. 6 enters the Larimer County Canal 1 mile below it. In exchanging most of the water is run through this outlet, in which a weir has been installed for measuring the flow. Water can also be run from Nos. 7 and 8, when they are finished, into the Larimer County Canal just below them. Another inlet from the North Poudre Canal fills reservoirs Nos. 3 and 4. The water in these two reservoirs is used directly through the ditch on the company's lands. Reservoir No. 11 is to be filled directly from the canal.

Reservoirs Nos. 12 and 13 are on the east side of Box Elder and Coal creeks, which unite several miles farther down the valley. In 1900 the North Poudre Canal was extended from its former terminus

at Box Elder Creek to these two reservoirs, and dams were built at the crossings of both creeks so that the reservoirs may be filled by the floods in the creeks as well as by the canal. They are drained into Coal Creek, making it possible to exchange with any of the several large canals below them.

The North Fork of Cache la Poudre River being the main factor in the filling of these reservoirs, the success of the system depends largely on the amount of water it furnishes, and this is uncertain. The company's reservoirs in the season for storing, like their canal during the irrigation season, are sometimes deprived of even the waters of the North Fork on account of the inadequate supply of the main river to meet the demand for filling reservoirs with earlier rights; while, if after these are filled there be any surplus in the main river, it can not be conducted to reservoirs Nos. 1, 2, 3, 4, 11, or the Coal Creek reservoirs, on account of their high location. The same has been true of all the others in the past, but in the future they may be filled from the main river by the Poudre Valley Canal. The six reservoirs used prior to 1902 were successfully operated, and the unusual season of 1902 was not a fair test. By the completion of the new reservoirs the storage capacity has been greatly increased, and while their utility remains to be proven it is believed by those who have studied the situations that the system will be a success.

The location of the reservoirs is excellent for exchanging with any other system in the valley, they being the highest, and any water stored may always be used advantageously somewhere. But, after all the company's reservoirs are full, the benefits to be derived from the lands under its canal still depend in a measure on the flow of the North Fork during the irrigating season, for the natural flow of this stream would probably often be too small to permit an exchange. The condition has been greatly improved, however, by the construction of the Sand Creek Ditch, which reenforces the flow of the Cache la Poudre, and water may be turned out of the North Poudre reservoirs for use by the owners of the Sand Creek Ditch through the Larimer and Weld Canal, while the North Poudre Company is receiving the water furnished by the Sand Creek Ditch from the head waters of the Laramie River. The company has desired a consolidation of these interests so as to insure such an exchange. It was proposed also that the capital be increased to enable it to enlarge its canal from a capacity of about 230 to 600 feet per second, and construct a masonry dam in the canyon of the North Fork one-half mile below the present head works, abandoning the expensive fluming and tunneling between these two points. The proposed dam would have to be 90 feet high in order to raise the water in the stream to the grade of the canal at that point. It is similar in design to the Home Supply Dam, in the Big Thompson River. No agreement has been reached,

but the exchange will doubtless be made each year, for while the various companies in the valley never cease to advance their own interests, they seem to be ready to enter into deals intended to benefit their neighbors so long as they do not lose any advantage.

The exchanges made by the company may be some in which all the systems in the valley are interested, and when this happens each of the reservoirs is simply reenforcing the canal first below it, to which it seems to properly belong. There being no reservoirs above the North Poudre Company's canal, it must be repaid for the water given from its reservoirs by water taken directly into its canal, and the lower canals, having received stored water, must give this from their share in the river. Thus all profit by the stored water, provided the supply of the North Fork be sufficient to repay the North Poudre Company. The Fossil Creek Reservoir, while above only two of the large canals, greatly facilitates exchanges by the company, as it adds materially to the storage capacity of the system. The completion of this reservoir and the acquirement of the right to use the Poudre Valley Canal has greatly improved the situation for the company.

Recently the North Poudre Company became owners of 41 per cent of the Poudre Valley Canal by the transfer of the Douglas Reservoir, which was constructed in 1902 by the company as No. 10 of their system, to the Poudre Valley Reservoir Company in exchange for $75,000 of the latter's stock, and by the purchase of $27,500 of additional stock. The first 17 miles of this canal will be finished before the spring floods of 1903, so that not only the Douglas Reservoir, but North Poudre reservoirs Nos. 5 and 6, and Nos. 7, 8, and 9 when completed, may be filled from the main river, leaving only those above the Poudre Valley Canal to depend on the North Fork as heretofore. This will be adequate for filling these upper reservoirs, and they will supply the company's lands, while those below the Poudre Valley Canal will be used in exchanges, which will no longer be limited to the flow of the North Fork.

The North Poudre Irrigation Company owns about 20,000 acres of land under its canal. This land, together with the water rights belonging to it, is being sold to individuals. Twenty-five shares of stock are sold with each 80 acres; therefore this amount of stock is equivalent to an 80-acre water right. There are 320 water rights in the company. The entire capital stock of the company is $400,000. At present the company furnishes water to fulfill the conditions of about one-half of 30 water-right contracts sold prior to the transfer of the system to the North Poudre Irrigation Company. These old rights, which were originally acquired for $25 per right per annum, are gradually being surrendered in exchange for 20 shares of stock in the North Poudre

Company, which gives their owners a proportion of the stored water as well as of that from the canal.

In 1902 the company sold 10,000,000 cubic feet of water from their reservoirs to Mr. B. H. Eaton for $100 per million cubic feet.

The total cost of the nine reservoirs of the company already constructed is $201,500, or $4.77 per acre-foot. The six reservoirs used prior to 1902 cost approximately $3,500 for maintenance and operation.

DOUGLAS RESERVOIR.

The Douglas Reservoir is the property of the Poudre Valley Reservoir Company, having been purchased from the North Poudre Irrigation Company, who constructed it in 1902 as Reservoir No. 10 of its system. It is located in Dry Creek Valley, where there are low hills on the east side and the south end. The creek entering this basin at the north turns to the southwest, passing through a break in a little ridge on the west side. At this point an embankment 2,300 feet long was constructed, its greatest height being 34 feet. It is 14 feet wide on top, with slopes of 2 to 1 on both inside and outside. The dam is not yet riprapped, but will be protected by stone.

The outlet consists of a rectangular stone conduit 3 feet wide and 4½ feet high, with a floor and top of flagging and side walls of masonry. The stone gate well projects through the top of the dam at its inner edge. There are two oak gates covering the opening of the well into the conduit below it and sliding vertically in a wooden frame set against the wall. They are raised and lowered by screws at the top of the gate stems.

The basin is oblong in shape, with quite regular contours, and covers 586 acres. When the dam is riprapped it may be safely filled to a depth of 30 feet. The reservoir is the only one in the valley having a dam on the west side, and since the winds generally come from the west in this locality, it will not be subject to the beating of waves as much as it would were it situated on the east or south side of the basin. The capacity of the reservoir is 10,547 acre-feet, and its cost, including the land, was $50,000, or $4.74 per acre-foot. The cost of the dam alone was $22,000.

The failure to entirely fill the Larimer and Weld Reservoir in 1902 was a surprise to the irrigators under the Larimer and Weld Canal depending upon it, but instead of becoming discouraged they immediately commenced preparations for additional storage works. This was not done by either the Larimer and Weld Irrigation Company or the Larimer and Weld Reservoir Company, but by an entirely new organization, including largely the same parties interested in both companies, and incorporated as the Poudre Valley Reservoir Company. Their original plans, which are described fully in the description of

the Poudre Valley Reservoir site, were to construct storage works of large capacity east of Box Elder Creek, and also an inlet canal for filling them.

The capital stock of the company was $250,000, divided into 2,500 shares. The contract for the construction of the inlet was let for $200,000, 12¼ cents per cubic yard being stipulated for the earth work, 34 cents for loose rock, and 99 cents for solid rock. The canal was to be 30 feet wide on the bottom, 7 feet deep, and over 30 miles long. Its carrying capacity was to be 600 or 700 cubic feet per second. The company, not having sufficient capital for the completion of the work as at first planned, abandoned the idea of constructing a reservoir and instead made the arrangement, referred to above, with the North Poudre Irrigation Company by which it acquired the Douglas Reservoir. The inlet canal was to run just around and above the Douglas Reservoir, and water can conveniently be run into the reservoir from it. An agreement between the two companies was finally reached about March 1, 1903, by which the North Poudre Company agreed to transfer the reservoir to the Poudre Valley Company for $75,000 worth of their stock. The North Poudre Company also purchased an additional $27,500 worth of stock and became owners of 41 per cent of the stock in the Poudre Valley Company. It being proposed to enlarge the reservoir, the North Poudre Company also agreed to have the reservoir surveyed for storing 10 feet in depth in addition to the present capacity at the 30-foot contour.

This transfer will be an advantage to both companies, for the North Poudre Company can well spare one reservoir from its large system and will now be able to use the large Poudre Valley Canal for filling reservoirs Nos. 5, 6, 7, 8, and 9 of its system from the main river. The Poudre Valley Company could not at the time secure the capital for the completion of its proposed work, but can now have a reservoir large enough for its needs. The first 17 miles of the Poudre Valley Canal has been completed, and it will supply enough water to fill the Douglas Reservoir and the reservoirs of the North Poudre Company referred to. In constructing the canal it was necessary to remove much more rock than was at first expected, and the cost up to the present has been $450,000. The canal will probably never be extended as first planned. (Pl. III, fig. 2.)

The Douglas Reservoir may supply the Larimer and Weld Canal without exchange by running the water down Dry Creek, although it is possible that the water will be run to the Larimer County Canal and the same amount taken from the reservoirs of the Water Supply and Storage Company for the Larimer and Weld Canal.

The Poudre Valley Company was wise in constructing a large inlet, for as it can expect to receive flood water only it must be able to take large quantities in the short time the floods last.

The embankment of Douglas Reservoir is across Dry Creek, which

may furnish some water for filling the basin. The Larimer and Weld Reservoir has the first claim on this water, but since the two reservoirs are owned by practically the same interests no difficulties are likely to arise in any case.

WARREN LAKE RESERVOIR.

The Warren Lake Reservoir is the oldest in the Cache la Poudre Valley, and is the only one which was given a decree with the ditches in 1882. The decree, unlike those given to the other reservoirs, entitles it to be filled by a certain flow through its inlet instead of allowing it a certain volume of water from the river, intended to be equal to the capacity of the reservoir. The decreed right dates from April 15, 1875, and is for 880 statute inches or 22.92 cubic feet per second. The decree also states that this is based on its area of 110 acres covered to a depth of 5 feet, which would be a volume of 23,958,000 cubic feet or 550 acre-feet. At present 8 feet of water can be drawn off. It would require a little over twelve days to store the given volume at the given rate of flow.

The embankment is several hundred feet long and curves around the northeast corner. It is 10 feet high and has a slope of 1½ to 1 on the outside, while its inner face is a rubble masonry wall almost perpendicular. The width on top, along which a public road runs, is 24 feet. The gate slides in a wooden frame against the inner face of the wall and covers the upper end of the outlet conduit. It is raised by a screw at the top of this frame. The reservoir is used in connection with the Larimer County Canal No. 2, and is owned by the Warren Lake Reservoir Company. It supplies only lands near the lower end of the canal.

CLAYMORE LAKE RESERVOIR.

Claymore Lake is situated on the lower side of the Cache la Poudre, just outside the foothills, and belongs to the Pleasant Valley and Lake Canal Company. It is just above the canal and aids in the irrigation of the land under the canal below the reservoir outlet. The reservoir has a small embankment. The area of the high water surface is 69 acres, and its filing is for 39,000,000 cubic feet or 895 acre-feet, and its capacity is claimed to be 1,148 acre-feet; but both of these are probably too high.

WINDSOR LAKE RESERVOIR.

Windsor Lake is located at the town of Windsor and should not be confused with the Windsor Reservoir 3 miles north of it. It is owned by a number of irrigators under the Cache la Poudre Canal No. 2, and is between the canal and the river. These irrigators exchange their rights in the canal for the right to fill the reservoir from the canal at the time of the spring floods, which allows them to use the water at their convenience. The lake also receives considerable water from seepage.

The reservoir was originally a natural lake and was converted into a reservoir impounding 6 feet of water covering 150 acres. Its capacity is estimated to be 918 acre-feet. It irrigates 640 acres of land, the entire potato crop of which depends upon it. Ten acres of fruit trees are kept alive by running water to them until late in the fall, which prevents them from dying during the winter.

The reservoir did not cost over $1,000, and it is valued at $15,000. The cost of maintenance is about $25 per annum, and as there is plenty of water, each irrigator uses water as he needs it without its being measured.

The wooden head gate which serves as the outlet is placed in a flume 4 feet wide and 16 feet long, made of 2-inch plank. A slight embankment made of brush extends for 75 feet on both sides of the head gate, although the flume is placed in a cut. The gate is raised by a lever turning a pinion gearing with a rack on the gate stem.

WOOD RESERVOIR.

The Wood Reservoir is owned by A. J. Eaton. Seepage alone is its source of supply. It is filled at least once each year and is kept fairly well filled, except when the demand on it is heavy. Its area is 120 acres and its depth 8 feet. The basin is entirely natural and an outlet made of 3-inch lumber was the only construction work necessary. It is the sole dependence of 600 acres, and in 1901 210 acres of this was in potatoes, which received plenty of water, and at the same time a neighbor was furnished water from the reservoir for 15 acres of potatoes.

The outlet cost $200, and the total cost was not over $2,000. The value of the water furnished annually by it is $2,000. The claim of the reservoir is for 120,000,000 cubic feet or 2,755 acre-feet, but this capacity is too large for the dimensions given. It is probable that the capacity is something less than that given.

LAKE LEE.

Lake Lee is a natural basin through which the Larimer and Weld Canal runs. The only artificial work is a set of wooden gates in the canal about 200 feet below the lake. The gates will hold a head of 8 feet and by so doing the flow in the lower end of the canal is better regulated. The owner of the reservoir is the Larimer and Weld Irrigation Company, and it is utilized in an exchange with the Cache la Poudre Canal No. 2. Water from the river belonging to the latter is taken by the upper canal and held in Lake Lee, and is paid for from the Windsor Reservoir. The head works consists of 5 gates of 3-inch plank, placed in a wooden flume 24 feet wide and 35 feet long and raised by a screw. Lake Lee is 67 acres in area and holds 321 acre-feet of water.

PROPOSED RESERVOIRS.

POUDRE VALLEY SITE.

The Poudre Valley Reservoir Company, which recently purchased the Douglas Reservoir, has only partially carried out its original plans to construct an immense system of storage works which would furnish water for their lands under the Larimer and Weld Canal. In brief, the papers filed stated that it was the intention to divert water from Cache la Poudre River by a canal or inlet ditch, to be constructed with its head gate in sec. 10, T. 8 N., R. 70 W., and to secure flood waters from Dry Creek, Box Elder Creek, and all draws crossed by the inlet ditch, for storage in three reservoirs to be constructed in secs. 13, 14, 23, 24, 25, 26, and 36, T. 8 N., R. 68 W., and sec. 31, T. 8 N., R. 67 W. The company reserved the right to acquire, by purchase, donation, or otherwise, rights of appropriations of water from adjacent sheds and appropriations for other proposed enterprises surveyed in the same location and to acquire the use of any canal under the reservoirs.

The sites were surveyed, and the areas, depths, and capacities of the basins are given, as follows:

Capacities of Poudre Valley Reservoir sites.

Site.	Area.	Depth.	Capacity.	
	Acres.	*Feet.*	*Cubic feet.*	*Acre-feet.*
No. 1	159	26	101,930,400	2,340
No. 2	75	19	33,105,600	760
No. 3	983	68	1,273,694,400	29,240
Total	1,217	...	...	32,340

No. 3 includes two basins. These basins are natural depressions, and the reservoir as proposed was to have two embankments, one at the north end of No. 3, about one-half mile in length, and another at the southeast end of the basin, connected with No. 3, about 500 feet in length. These sites, which compare in size with Boyd Lake, unlike other large sites, have not been under consideration for many years, but seem to have just recently come to the notice of the public. The Poudre Valley Company originally stated that if after the reservoirs were completed and successfully operated the conditions justified such a measure, its canal would be extended to the east, crossing the Union Pacific Railroad north of the town of Pierce, to cover much valuable land above the Larimer County Canal.

LINK LAKE SITES.

A claim was filed in 1902 for the Link Lake and Ditch System, the intention being to connect eight basins in the mountains as one system. All of the basins are small, and the capacities claimed were given as follows:

	Acre-feet.		Acre-feet.
No. 1	1,060	No. 6	300
No. 2	1,400	No. 7	440
No. 3	525	No. 8	2,000
No. 4	500		
No. 5	700	Total	6,925

These sites are in secs. 4, 5, 6, 7, 8, and 9, T. 8 N., R. 76 W. Nos. 1, 2, 3, and 4 are situated on Rawah Creek, a tributary of Laramie River. It is the intention to discharge the water from one basin into another successively. At No. 4 a ditch is to convey the water to the Laramie River Ditch of the Water Supply and Storage Company. Nos. 5, 6, 7, and 8 are above the grade of the ditch at different points along its line and are to be emptied into the ditch. The intention is to use the Laramie River Ditch and the Cache la Poudre River in conveying the water to lands on the plains outside the foothills. Rawah Creek enters the Laramie River below the head of the Laramie River Ditch, and therefore the scheme, if carried out, will not affect existing interests in Colorado.

SAND CREEK SITE.

In 1901 a filing was made by R. Q. Tenney and B. H. Eaton for a reservoir located on Sand Creek with the ditch of that name, which is now in operation. The capacity given was 448,394,457 cubic feet. The water stored would be taken from Sand Creek and used in the Cache la Poudre Valley.

NUN CREEK SITE.

There is a proposition to construct a reservoir, to be known as the Nun Creek Reservoir, which is to be filled from a ditch from Nun Creek. Nun Creek is a tributary of the Laramie River. The water would be taken across the divide and discharged into the Middle Fork of the Cache la Poudre. The proposed ditch and reservoir are to be located in the vicinity of the Bob Creek Ditch owned by the Larimer and Weld Reservoir Company.

SEELEYS LAKE SITE.

Seeleys Lake is located a few miles northwest of Greeley under the Cache la Poudre Canal No. 2, and has been filed upon for a reservoir for irrigation, its capacity being given as 90,000,000 cubic feet, or 2,066 acre-feet. At present it is a natural lake used for fishing and boating and covers about one quarter section. It will probably be developed in the near future.

RESERVOIRS ON BIG THOMPSON RIVER.

LAKE LOVELAND.

Lake Loveland is now the property of the Greeley and Loveland Irrigation Company, which owns the Loveland and Greeley Canal and the Barnes Ditch. It was purchased with the rest of the system about March 1, 1903, from the New Loveland and Greeley Irrigation and Land Company. Before the transfer, farmers under the canal had purchased all the rights in Lake Loveland except 65. Fifty-three of the remaining rights were bought by the farmers for $750 each. The remaining 12 were reserved on account of a contract with the Loveland Sugar Company. The price paid for the old company's interest in the entire system was $48,500.

The Loveland and Greeley Irrigation and Land Company, which developed this reservoir site, represented practically the same interests as does the Colorado Mortgage and Investment Company of Denver, and was known locally as the "English Company" and its canal as the "English Ditch." They originally purchased the old Larimer County Irrigating and Manufacturing Ditch, commonly called, from its builder, the Chubbuck Ditch, and enlarged it, making it what is now the upper end of the Loveland and Greeley Canal. The rights in the old ditch are now known as the Chubbuck rights in the canal. The same company also purchased the Barnes Ditch, which they enlarged so that it might be used as the inlet to Lake Loveland. In fulfilling conditions of agreements in both these purchases the owners of the canal furnish water free and for all time to the owners of the original rights in the two ditches, but these do not extend to the reservoir, as it was not constructed until 1896, several years after the agreement.

In 1891 parties filed papers of incorporation as the Farmer's Irrigating and Reservoir Company, intending to utilize what is now the basin of Lake Loveland, and claimed over 500,000,000 cubic feet of water from the Big Thompson River to fill it. It was to be called the Hays Reservoir. Again in 1893 it was filed on as the Peoples Reservoir, 566,715,512 cubic feet being claimed as the capacity. These plans were not carried out and it was left for the Loveland and Greeley Company to develop the site at a later date. The natural lake was known as Kilburn Lake and it was ideally located for a reservoir to be used in connection with the Loveland and Greeley Canal. The capacity was greatly increased by the construction of an embankment along the rim of the basin at the south side for a length of 400 feet, the greatest height being 18 feet. It is 20 feet wide at the top, along which runs a county road, and has an outside slope of 1½ to 1 and an inside slope of 3 to 1. The inner face is well riprapped with loose stone and when the reservoir is full there is only 15 feet of water against the dam. (Fig. 6.)

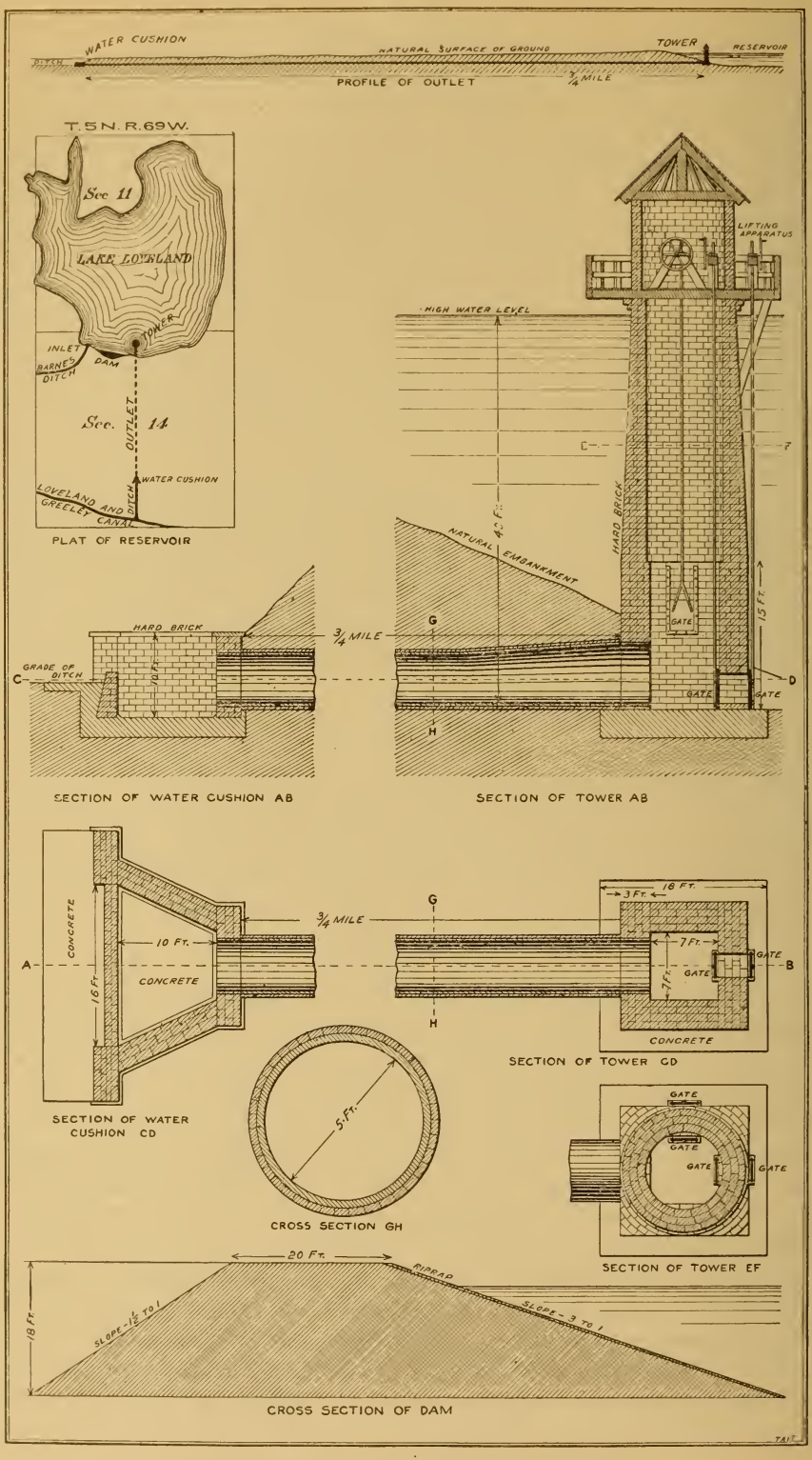


FIG. 6.—Design of dam and outlet of Lake Loveland.

The outlet, instead of being made through or below the dam, was made through the natural bank at the south side near the east end of the dam. The conduit is a pipe of hard brick laid in cement. The inside diameter of the pipe is 5 feet and it is about three-quarters of a mile long, running under one end of the town of Loveland in a tunnel. At the edge of the reservoir the outlet is 45 feet below the surface of the ground, which slopes gradually toward the Big Thompson River, the outlet being only 12 feet below the surface at the lower end. Below this point the water is carried through an open cut for a distance of about one-fourth of a mile until it joins the Loveland and Greeley Canal. Unusual care was taken to prevent the water issuing from the conduit from cutting out the ditch. An apron of concrete 2 feet thick was laid extending 15 feet below the outlet and on this was built a transverse retaining wall with wings extending out at angles, all of hard brick and capped with stone. These walls are 2 feet thick and 10 feet high. Near the lower edge of the concrete apron a low brick wall was placed across the water channel between the ends of the wing walls so that it would check the force of the water spouting from the outlet pipe. This wall is 4½ feet high and is 2 feet thick at the base and slopes to a width of 13 inches on top. It is supported on the lower side by concrete and its top is only 6 inches above the grade of the ditch below it.

The upper end of the outlet extends into a tower of hard brick from which the gates are operated and which is about 150 feet out from the water's edge when the reservoir is full, making it necessary for the operator to use a boat to reach it. The tower is built on a concrete foundation 3 feet thick and is square for a height of 15 feet at the base. For this distance it is 7 feet square inside. Above the tower is round and is 8 feet in diameter on the inside. The wall is 3 feet thick at the base and slopes to a thickness of 16 inches at the top, the slope being on the outside. The total height of the brickwork is 51 feet. The tower is covered by a conical roof, and at a height of 42 feet above the base a wooden floor is placed around the outside like a veranda and also on the inside. The gates are operated from this floor or platform, which is 2 feet above the high-water mark. The outlet pipe is enlarged at its opening into the well and tapers for a distance of 16 feet until it becomes 5 feet in diameter. The water enters the tower through two openings in the walls of the lower square portion, one of which is at the bottom on the north side while the other is 3 feet above the base on the west side, each being 2½ feet wide and 3 feet high. These openings are covered by both inside and outside gates. The first inside gates were of oak, 3 inches thick, with iron straps bolted to them, but these leaked and after being used two years they were replaced by 2-inch cast-iron gates backed by 2½-inch oak. The outside gates were one-half inch thick and worked in brass

grooves in a frame placed against the brick wall, and were strengthened by 2-inch oak bolted to the iron. After being used two years one of these gates was crushed in with a head of 40 feet of water on it. The total pressure on the whole area of the gate was 18,047 pounds. The inside gate held, however, and no water was wasted from the reservoir. These gates were replaced by 1-inch cast-iron gates having wrought-iron ribs bolted to the back of them, and these have given no trouble. The gate stems are 2-inch steel rods braced at

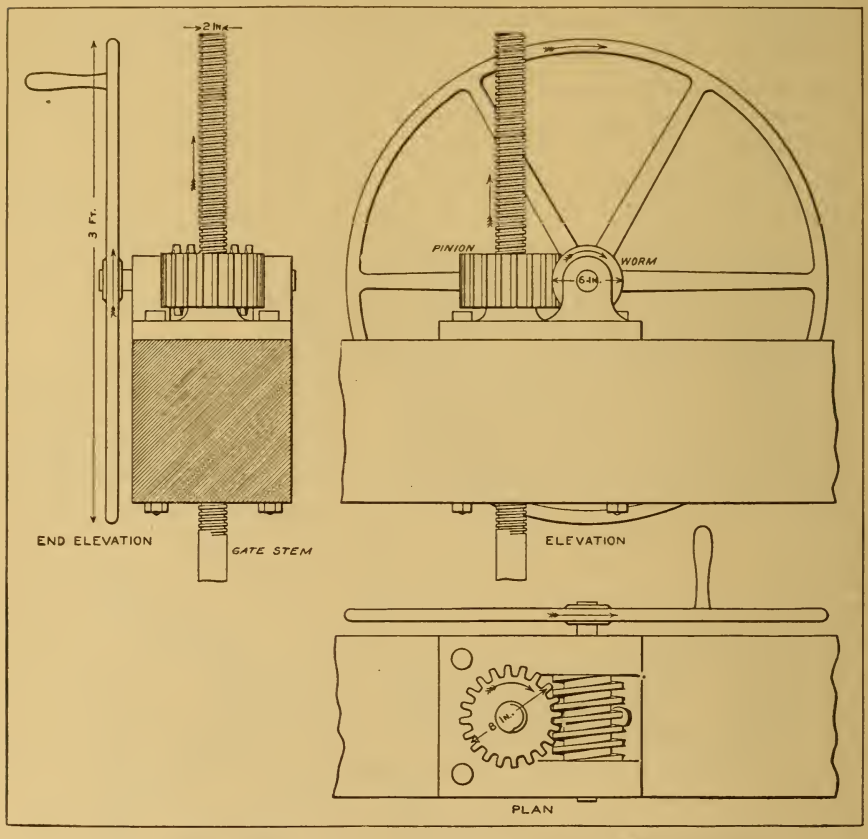


FIG. 7.—Design of lifting apparatus used at Lake Loveland and Mariano reservoirs.

three points by iron collars fastened to the brick wall to prevent them from buckling when under thrust.

The lifting apparatus is of necessity very powerful (fig. 7). The upper end of the gate stem is threaded and passes through a pinion which acts as a nut rotating horizontally, but having no vertical motion. The pinion gears with an endless screw or worm at right angles to it and on the same shaft with a large handwheel which is turned by the operator. The wheel is 3 feet in diameter, the worm 6 inches, and the pinion 8 inches. The pitch of the threads on the worm and of the

teeth of the pinion is 1 inch. Each gate has its own lifting device, two being inside the tower and two outside. When those outside were first used it was found necessary to brace the platform on which the apparatus rested, as the pressure on it in raising the gates was about to pull it down.

The basin of Lake Loveland is exceptionally fine, being in general round and shaped like a bowl. When the reservoir is full the water is 40 feet deep over the outlet, and is 3 feet below the top of the embankment. The area of the water surface at this height is 492 acres. The reservoir has been surveyed and its capacity determined for each foot contour. The following table gives the capacity in cubic feet and acre-feet for each 5 feet in depth above the outlet:

Capacity of Lake Loveland at various contours.

Feet.	Cubic feet.	Acre-feet.	Feet.	Cubic feet.	Acre-feet.
5	18,405,762	423	25	247,729,574	5,687
10	64,420,169	1,479	30	323,672,814	7,430
15	118,925,440	2,730	35	409,185,640	9,393
20	180,215,950	4,137	40	575,596,640	13,212

There is in addition to this 24,642,360 cubic feet or 566 acre-feet, which is below the outlet and can not be drawn off.

The dam of Lake Loveland was comparatively inexpensive, the elaborate outlet works with the long tunnel making the greater part of the cost of construction, which was $125,000. The cost per acre-foot of the capacity of the reservoir is $9.46. One 80-acre water right entitles its holder to one three-hundredth of the water in the reservoir, or 45.91 acre-feet when the reservoir is full. The annual assessment on each right for maintenance is $10. The company spared no expense in making the outlet works substantial and in keeping the reservoir in good condition, giving it the finished appearance of a public rather than a private work. The superintendent of the reservoir lives in a cottage on the premises, his services being required during the entire year.

Lake Loveland is filled from the Big Thompson River. The Barnes Ditch, its inlet, heads in the river about 3 miles west of the reservoir and runs along the south side of it over the outlet. Water is turned into the reservoir through a flume which extends over the bank for a distance of over 100 feet to prevent the water from cutting away the bank. The inlet gate is at the upper end of this flume and is near the west end of the dam. The Barnes Ditch has a capacity of 450 cubic feet per second, but the greatest amount that is ever run through it is less than this, the owners thinking it prudent not to test the ditch to its full capacity until the banks have become finally settled. The ditch runs around a steep bluff, at which point it broke several years

ago, costing the Loveland and Greeley Company, which then owned it, $2,000 for repairs, as well as the loss of water for storage. The reservoir has no decree from the court for filling, but in years of an ordinary water supply it has been filled. In 1899 and 1900 it was filled to its utmost capacity, in 1901 to a depth of 36 feet, and in 1902 to a depth of only 13 feet. In the fall of 1902 twenty irrigators under the Loveland and Greeley Canal commenced work on the Eureka Ditch which will bring water from the Grand River drainage over the divide to the Big Thompson at a place known as Flat Top. One mile of ditch 6 feet wide has been completed, and work will be continued in the coming summer. They expect to store the water obtained in Lake Loveland or in the Seven Lakes Reservoir. Previous to 1901 only 135 rights in the reservoir were sold, but with the advent of the sugar beet in that year 40 rights were sold at $750 each. In 1902 more were sold at the same price, 20 going to irrigators under the Louden Canal to be used by exchange. The Louden Canal and the land under it are above Lake Loveland, but the water is taken from the reservoir into the Loveland and Greeley Canal and an equal amount diverted from the river into the Louden Canal. Such an exchange is always possible, for the former is entitled to 78.02 cubic feet per second from the river before the latter is entitled to anything. A similar exchange is made with irrigators under the Barnes Ditch, who own a few rights. All the other rights were sold to irrigators under the Loveland and Greeley Canal, the water being run into the canal about 1½ miles below its head, so that it is possible for the reservoir to supply water to practically all the users under the canal.

The water is distributed from the reservoir by making runs when they are called for by a majority of the users. The main crop under the lower end of the canal being vegetables, which require late irrigation, and that under the upper end being largely cereals, which require early irrigation, some conflicts regarding the time of the runs have arisen, but in the two past seasons sugar beets have taken the place of wheat to a great extent in the upper district, and this will probably have a tendency to lessen the difficulties.

In 1901 runs were made from the reservoir as follows:

Water used from Lake Loveland in 1901.

	Acre-feet.
July 21 to 26, inclusive	2,107
August 2 to 6, inclusive	1,810
August 14 to 18, inclusive	1,589
August 26 to 31, inclusive	1,930
September 6 to 12, inclusive	1,814
Total	9,250

Water remained in the reservoir at the end of the season to a depth of 9.5 feet.

In 1902 the runs were as follows:

Water used from Lake Loveland in 1902.

	Cubic feet per second.	Acre-feet.
To Louden Canal, by exchange, July 23 to 26	12	95
To Loveland and Greeley Canal, Aug. 2 to 6	124.5	1,235
To Louden Canal, by exchange, Aug. 9 and 10	24.9	96
To Loveland and Greeley Canal, Aug. 13 to 20	100	1,587
To Barnes Ditch, by exchange, Aug. 21 to 23	5	30
To Louden Canal, by exchange, Aug. 28 to 30	10	59
Total		3,102

Water was formerly measured by a weir in the outlet ditch of Lake Loveland, but much trouble was caused by the ditch back of it becoming filled up with mud and gravel. The grade of the ditch is high at this point, and doubtless the velocity of approach of the current was too great, while if the conditions for accurate measurement had been considered in placing the weir no trouble of this kind would have occurred. It has been replaced by a measuring flume, which has been found to be more practicable. Water run for the Chubbuck rights is measured by the miner's-inch method, but under the rest of the Loveland and Greeley Canal weirs are used in the laterals.

The decreed priorities of the Loveland and Greeley Canal are among the oldest from the Big Thompson River, and at one time the company attempted to store water from the canal rights. The priority of the canal of the Home Supply Company is very late, but its reservoirs both have rights established by decrees, and Lake Loveland having none, they should always be filled first. So the Home Supply Company, fearing that the supply would not be sufficient to fill its reservoirs later, and considering the practice an infringement upon its rights, succeeded in getting an injunction stopping this manner of filling Lake Loveland. A final decision was rendered by the supreme court of the State prohibiting the use of the water decreed to the Loveland and Greeley Canal for storage purposes. A similar difficulty occurred recently between the Loveland and Greeley Company and the Seven Lakes Reservoir Company, in which the former was in the same position as the Home Supply Company in the first case. The details and results of the later case are discussed more fully in connection with the Seven Lakes Reservoir.

Another question settled by the court was in regard to running water through Lake Loveland for fish. The Home Supply Company objected, claiming that more water was run into the reservoir than was let out of it. The court permitted this use of the water, but ordered the water commissioner to keep measurements of the flow in both the inlet and outlet ditches in order that the equality might be maintained. This officer, intending to carry out the order in spirit

rather than in detail, simply maintained a constant depth of water in the reservoir, by which the Loveland and Greeley Company gained an amount for storage equal to the loss from seepage and evaporation during the time that water was run through it.

CONSOLIDATED HOME SUPPLY DITCH AND RESERVOIR COMPANY'S SYSTEM.

The Consolidated Home Supply Company owns the Lone Tree and Mariano reservoirs, the Home Supply Canal, and the Home Supply Reservoir Ditch. The members of the company are farmers, using the water under the canal. The system is similar to that of the Water Supply and Storage Company in many respects. The reservoirs are used to reenforce the canal during the whole season, becoming almost the sole dependence in the latter part, and the water rights pertain to both reservoirs and canal. There are 2,001 shares of stock in the Consolidated Home Supply Company, 15 representing a 160-acre water right. The priority number of its canal is 53, and it is one of the latest in the district, but its reservoirs have made the system one of the most successful in the State. The Mariano Reservoir was constructed in 1881 and the Lone Tree Reservoir was constructed in 1888. Both are below the company's canal, the former being just outside the foothills between the canal and the Big Thompson, while the latter is on the south side of the canal at a point several miles farther down its course.

LONE TREE RESERVOIR.

The Lone Tree Reservoir is the largest and most important of the two, and shows well what can be done at a very small cost in utilizing a natural lake for storage. The reservoir basin is entirely a natural depression, and contained water before it was used as a reservoir. The Home Supply Canal runs along the north end of the reservoir and across the fill over the outlet. It was necessary to make an open cut above the outlet 20 feet deep and several hundred feet in length. The outlet consists of a stone-arched conduit, 150 feet in length and 3 feet wide by 5 feet high. Cement collars were placed around this at intervals, and at both ends masonry walls 3 feet thick were constructed across the cut, but no wing walls are attached. The tops of these walls are at the surface of the ground, the earth being filled in between them to its original height.

The two gates are of wood and cover the upper end of the conduit. They slide in a frame made of 12 by 12 inch timbers placed against the upper wall. The gate stems are 4 by 4 inch timbers, terminating in 1½-inch iron rods at the top. These rods work in iron nuts, which are turned by a spanner having a handle about 3 feet in length. While the reservoir is one of the largest in the valley, only 16.5 feet

of water is drawn from it, and so the pressure on the gates is not too great for this form of lifting apparatus.

The reservoir covers 600 acres, and has a capacity of 3 2,040,000 cubic feet, or 9,002 acre-feet, although the present outlet is not low enough for all of this to be drawn off. It is filled from the Big Thompson River by the Home Supply Canal, the water being turned directly into the reservoir through the inlet at the north end. The reservoir was given a decree, under date of August 31, 1881, for 400,000,000 cubic feet, and in the official record of this the name given is the Farwell Reservoir, although it is now known altogether by the name under which it is described.

The capacity of the reservoir can be increased in two ways, and the company is at present considering these with a view to adopting the best plan. One plan is to construct a 6-foot embankment along the south side, raising the height to which water can be stored, and the other is to drain the basin lower. The decree entitles the company to store water in the reservoir to a certain height above the lowest portion of the basin, but the present outlet drains only one-half of this depth of water. It is required that 1½ feet of water be left in the basin for the protection of fish, and the outlet could be 17 feet lower and still leave this amount. The volume gained by the additional 6 feet on top would increase the capacity more than the additional 17 feet on the bottom on account of the great difference in areas, and the company realizes that the former device would be the cheapest in the end; but there are other things to be considered. If the service of the reservoir is increased by draining lower, it may be filled entirely each year on its present decree, which practically insures its being full in seasons of an ordinary supply; but the additional amount at the top could not be stored until nearly all the other reservoirs were filled, as it would be a later appropriation. The available amount for storage from the Big Thompson being about all appropriated, this could not be depended on, and for this reason the plan of draining lower is favored. While this action may be entirely legal, the company would acquire the use of water which has previously been used beneficially by someone else.

The company's engineer made surveys in the fall of 1902 relative to the enlargement of the reservoir, and the plan recommended by him for draining the present unavailable water was to construct a new outlet of iron or sewer pipe 17 feet lower, tunneled directly under the present one, which would be retained. The new outlet would have a comparatively small capacity, and need be used only when the water surface fell below the upper one. It would be necessary to extend this pipe for a distance of 1,000 feet or more above the present outlet gates, and probably an open cut above this would be necessary. The pipe would also have to extend some distance below the present gates before meeting the grade of the outlet ditch. The regulating gate

was to be at the upper end of the pipe, and to be operated from a platform or tower to be reached by a boat. This plan was estimated to be cheaper than the reconstruction of the present outlet in a deeper cut, but the latter plan would probably be the more satisfactory when completed, and eventually cheaper.

The company paid $500 for the site of Lone Tree Reservoir, and the cost of making the cut and building the outlet works was $10,000, making the cost per acre-foot $1.67. A very expensive fill was made in 1901 to carry the Home Supply Canal along part of the edge of the reservoir in place of through a flume which had become unsafe, but the cost of this is not included in that of the reservoir.

MARIANO RESERVOIR.

The Mariano Reservoir received its name from a Mexican named Mariano, who at one time constructed a ditch from the Big Thompson River. The reservoir is also known as Bodecker Lake.

The embankment of the reservoir is almost on a section line and the public road is on top of it. It is 600 feet long, 24 feet high, and 15 feet wide on top, and has an inside slope of 2½ to 1 and an outside slope of 2 to 1. This embankment is on the east side, where it is subject to severe wave action, and therefore it has been well riprapped. It was also given a height of 7 feet above the high-water mark.

The outlet was made through the embankment, and consists of an arched stone conduit having cement collars at intervals to prevent water following along the outside. The conduit is 2 feet wide and 3 feet high, and the lower end projects into a wall 2 feet thick. The gates cover the upper end of the conduit and operate in a well or tower inside the reservoir. The lower 9 feet of this structure is a masonry well 3 by 16 feet inside, while the upper 9 feet is a structure built of 12 by 12 inch timbers. The wall of the well next the embankment is uniformly 2 feet thick, while the others have a batter on the outside. The end walls are 2 feet thick at the top, and the upper one is 4 feet thick. The water enters the well through openings in this upper or outside wall, the earth of the embankment partly surrounding the others. The lifting apparatus for the gates is on top of the tower and is reached by a plank walk from the embankment.

The gates are of wood, and their stems are 2-inch iron pipes. The mechanism for lifting one gate consists of a worm turning horizontally and gearing with a rack fastened rigidly to the top of the iron pipe. The rack is held in its place so that its teeth mesh with the threads of the worm by a roller at its back, and a wrench fitted to the end of the shaft carrying the worm further increases the power. The worm is 4 inches in diameter, and the rack must necessarily be as long as the lift of the gate. Lifting devices of this form were originally used for both gates, but one was broken and it was replaced by an apparatus

smaller but similar in form to those used at Lake Loveland (fig. 7, p. 58). In place of the rack there is a steel rod at the top fitted inside the pipe and bolted thereto. This rod, being threaded, works in a brass nut which is the center of a pinion gearing with a worm at right angles to it. The power applied to a large hand wheel turns the worm, the two having a common shaft.

The reservoir is 373 acres in area, and is 16½ feet deep over the outlet. Its capacity is 4,140 acre-feet. The reservoir could be enlarged in capacity 30 per cent by raising and lengthening the dam. The decreed priority of the reservoir is the second on the stream, dating from October 1, 1875, and the amount decreed is for 180,865,000 cubic feet. The preceding priority is for a small amount, so that the chances of the reservoir being filled are very good.

The company paid $6,000 for the site of the Mariano Reservoir and the perpetual right to fill it through the Rist Ditch, which it agrees to enlarge and maintain. The reservoir could be conveniently filled through any of the three other ditches which pass around a point of the foothills at the west end of the reservoir. The highest of these, the Handy Ditch, is within a half mile of the reservoir, and the Home Supply Canal and the South Side Ditch are successively below it. The Rist Ditch has a capacity of only 66 cubic feet per second, but it runs just around the reservoir below the other three, and the water has to be carried only about 3 miles from the river, while if the company's canal were used it would be carried a much greater distance.

The dam of the reservoir cost originally $4,000, and it was riprapped later at a cost of $500, thus making the total cost of the reservoir $10,500, which does not include the cost of enlarging the inlet. The cost per acre-foot stored is $2.54.

HOME SUPPLY DAM.

The Home Supply Dam is located at the mouth of the canyon of the Big Thompson River, and its purpose is to divert the waters of the stream into the head of the Home Supply Canal. The amount of water impounded by the dam is of no consequence, as the canyon above it is very narrow and the fall of the stream great. While the dam was not intended for storage purposes, it is of a type well adapted to mountain streams for either storage or diversion purposes, and it is therefore described in this connection.

The Home Supply Canal was designed to irrigate the greater part of the valuable land between the Big and Little Thompson rivers, and runs near the highest portion of the slight ridge between these two streams, irrigating land both north and south of it. After leaving the river it runs south some distance through the narrow tract of flat land between the mountains and foothills, until it drops 15 feet or more into Cottonwood Creek, a tributary of the Big Thompson River,

and this natural channel is used in passing through the range of foothills. The dam raised the water to the head of the canal, over 40 feet above the channel of the river, and it might seem that this was unnecessary, since a drop is allowed at a lower point; but it was desirable in order that the canal might pass behind the range of foothills instead of along their eastern slope, where a great deal of expensive work

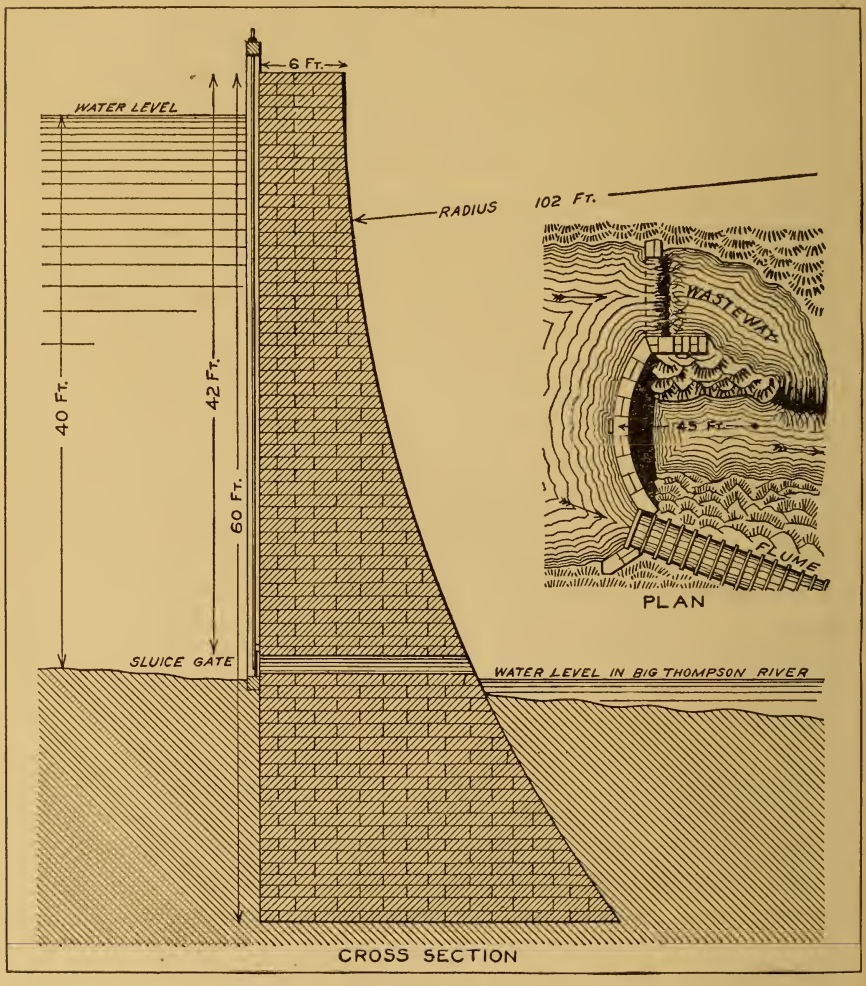


FIG. 8.—Design of Home Supply Dam.

would have to be done in fluming, tunneling, and maintaining the canal. It was desirable also to construct such a dam instead of continuing the canal farther up the stream until it should meet the channel, because the sides of the canyon are nearly perpendicular and of solid rock, and the construction and maintenance of a canal would be difficult.

Two dams have been constructed, the first having been destroyed.

The first dam was of the same type as the present one, but it was not of solid masonry and did not extend to a foundation of bed rock. It was formed by two walls of masonry with a filling of concrete between them, but the main cause of the disaster was the inadequate foundation rather than the material used in the construction. The new dam was constructed of solid masonry founded on bed rock 15 feet or more below the natural channel of the stream and butting against solid rock on both sides of the canyon (fig. 8). The dam is 60 feet long on top, and the radius of curvature horizontally is 45 feet. The upper face of the dam is perpendicular, but the lower face has a vertical curvature with a radius of 102 feet, which increases the thickness of the dam from 6 feet at the top to 26 feet at the base. A sluiceway 15 inches in diameter was made at the natural surface of the stream 42 feet below the top of the dam. The dam is about 15 feet thick at this point. The sluice gate is on the upper side and is controlled from the top of the dam. It is used mainly to lower the water surface to break ice which might endanger the masonry rather than for scouring.

The dam raises the water level over 40 feet, so that it will enter the head gate of the canal, which is on solid rock at the south end of the dam instead of in the dam itself. The water is carried for several hundred feet around the rock at the mouth of the canyon in a flume. The waste way is at the north end of the dam and consists of a low masonry wall 6 feet wide built on the solid rock. It is 3 feet below the top of the dam and 30 feet wide and carries the ordinary surplus flow, but at times water runs over the entire top of the dam. When dams of this type are constructed for storage purposes the waste ways are usually made large enough to carry the greatest surplus flow, so that in times of floods the dam will not be subject to a shock in addition to the pressure of the water against it.

It is well recognized that dams of this type do not act exactly as do bridge arches in sustaining a vertical pressure. The pressure of the water is perpendicular to the face of the dam at any point, but the transmission of this pressure as a thrust on the banks at the ends of the dam is in some measure obstructed by the weight of the dam itself on its foundation. It is quite probable, however, that the dam was designed so that it would withstand a certain steady pressure if it were straight, and that the arch is an additional precautionary measure. The dam contains 1,400 cubic yards of masonry.

OPERATION OF THE SYSTEM.

The system of distribution of the Consolidated Home Supply Company is one that has given universal satisfaction, a condition which exists for two reasons—the unusual liberty allowed the irrigator and the abundant supply of water furnished—for difficulties always arise as soon as water becomes short whether there is any unfairness or not.

The system of distribution has been compared to a banking system. Before turning any water out of the reservoirs the available amount stored is conservatively estimated by the company's superintendent, and each shareholder is credited in that officer's water book with an amount proportional to the stock he owns. He may draw this amount as he chooses, either all at once or in parts, upon application to the superintendent, provided only that the total amount applied for by all the stockholders shall not at any time fall below 20 cubic feet per second. Each man's share is measured to him over a Cippoletti weir in his lateral and an account of it kept by the company, in order that it may not exceed the amount due him. If the first estimate of the amount in the reservoirs is found to be too small, the superintendent always being careful not to make it too high, another is made and a new account opened with each irrigator. If at any time the reservoirs are full and water would otherwise have to be turned down the river, the head gates are kept open and the water is run to the stockholders without charge and no account is kept of the amount. But if there is any room for storage in the reservoirs a charge is made for the water run to the stockholders directly from the river through the canal. Water is never run to any stockholder who may be in arrears with his assessment. A great variety of crops is raised under the system, and the result is that water is run from the reservoirs during most of the season. Water is run at the rate of 1 cubic foot per second to each 15 shares. In 1901 water was first turned out of the reservoir June 1, and it was run continuously for thirty-five days. The gates were opened again for ten days in July and August, and all the remaining water was run out in September. Both reservoirs were full that year, but in 1902 only 10 feet was drawn from Lone Tree Reservoir and 12 feet from Mariano Reservoir, each being considered only one-half full. In one dry year the head gate of the Home Supply Canal was never raised, the reservoirs being depended upon entirely to mature the crops, and the results were good.

The water stored in the Mariano Reservoir is exchanged with some of the ditches on the lower part of the Big Thompson River, the rights of which are earlier than those of the company's canal, an amount equal to that run into the river for them being diverted at the head of the canal. The outlet ditch of the reservoir is about 2 miles long and joins the river above the head gates of the Loveland and Greeley, Farmers' Irrigating, and Hillsborough canals and several small ditches. Lone Tree Reservoir is so little below the Home Supply Canal that, instead of exchanging the water stored, it is used directly from the outlet ditch, which is known as the Home Supply Reservoir Ditch. It runs almost parallel with the main canal, and the small amount of land above it, together with that west of the reservoir, can be supplied from the canal reenforced by the Mariano Reservoir. Another reason

for not exchanging is that if the water had to be used in that manner the amount run might be limited by the amount of water in the river which the lower ditches have to exchange.

The reservoirs together hold 13,142 acre-feet, and their cost was $25,500, which is only $1.94 per acre-foot. The total assessment for maintenance of the entire system in 1901 was $4,000, and one-half of this can be considered the expense for the canal. Three times as much land is irrigated as could be with the canal alone. Land is worth two-fifths more with reservoir rights than without, the value under the company's system being from $40 to $160 per acre. In 1901 the price paid for one share was $90, but in 1902, on account of the increasing demand for water for the irrigation of sugar beets, it advanced to $125 and $150. The price paid for one share in 1903 was $255, which is equivalent to $1,912.50 for an 80-acre water right. Shares are sometimes rented to individuals who are not members of the company. In 1901 the price paid was $12.50 per share, but in 1902 as much as $20 per share was paid in the late season for the irrigation of sugar beets and potatoes. Since one share represents 6.56 acre-feet in the reservoirs, this is practically at the rate of $3.05 per acre-foot, for the water furnished by the canal was so small that it can be omitted in the calculation.

SEVEN LAKES RESERVOIR.

The Seven Lakes Reservoir was completed in the winter of 1900, and consists of six lakes connected and operated as one system. Its owner, the Seven Lakes Reservoir Company, originally intended to acquire Big Thompson Reservoir, or Cemetery Lake, which was to be included in the system as No. 5, but no agreement with the owners was reached, and it is not probable that it will ever be connected. No. 1 of the system was formerly the Louden Reservoir, and is also known as Donath Lake. It was purchased by the company and joined with the remainder of the system. It lies just below the Louden Lateral, the large lateral from the Louden Canal running east and irrigating lands on the Big Thompson slope, and its outlet ditch flows into No. 2, which is one mile south of it. Nos. 3, 4, 6, and 7 are just south of No. 2, and all are drained through the outlet ditch of No. 7 into the Loveland and Greeley Canal just below it. No. 1 has its own outlet works, but all the others are practically one basin, since they are simply connected by open cuts; and, having a common outlet at No. 7, the water stands at the same level in all. No. 2 is the largest in the system and the only one where an embankment was required.

The outlet of No. 1, or Louden Reservoir, was made through natural rock, and above the gate well consists of 150 feet of sewer pipe 2 feet in diameter, while below the gate well it consists of 8 feet of stone arch 2 feet wide and 2½ feet high. Retaining walls of masonry are

placed across the cut at both ends of the outlet, and the gate well is of masonry, is 3 by 3 feet inside, and has walls 2 feet in thickness. The concrete foundation under the well is 1 foot thick. The gate and its stem are of wood, and the former slides in a frame of timbers which extends to the top of the well. A simple screw lifts the gate.

The basin of No. 2 was formed by constructing an embankment across one of the numerous dry creeks, this one running into Boyd Lake to the east. This embankment is 687 feet long on the top, but the gulch narrows toward the bottom, making the embankment only 50 feet long at the base. It is 40 feet high, with inside and outside slopes of 4½ to 1 and 3 to 1, respectively. The site was plowed and the embankment was constructed in layers, sloping toward the inside, but it was not riprapped in any way. The outlet is not at the dam, but at another side of the basin through an open cut.

The outlet works at No. 7 consist simply of wooden head gates in the open ditch. There are two gates, each 3 feet square, placed at the upper end of a flume 7 feet wide and 6 feet deep. The flume is 22 feet long, and 16 feet below the gates a drop of 2 feet occurs. The flume is built of 2 by 12 inch plank and 6 by 6 inch sills, posts, and ties, the frames formed by the three latter being 4 feet apart. Sheet piling was driven at the bottom and sides of the frame at the upper end.

The following table gives the areas and capacities of the several basins:

Areas and capacities of Seven Lakes Reservoir sites.

Basin.	Area.	Capacity.
	Acres.	*Acre-feet.*
No. 1	65	1,148
Nos. 2 and 3	450	3,719
No. 4	80	689
No. 6	30	115
No. 7	25	114
Total	650	5,785

Twenty-eight feet of water is drawn from No. 1, but only a few feet can be drawn from the others, there being much unavailable water in them, the most of which is in No. 2. This is an undetermined amount and is included in the figures given in the foregoing table.

The price paid for No. 1 with its outlet ditch was $10,000. The remainder of the system, including the purchase of 800 acres of land, cost $30,000, the dam at No. 2 alone costing $4,400. Excluding No. 1 and assuming that only one-half the total capacity of the rest, except No. 1, is available, the cost per acre-foot for the system is $12.94.

The Louden Reservoir, or No. 1, has a priority decree dated February 24, 1883, for 50,000,000 cubic feet, this right being the sixth on the Big Thompson. When securing this property the company also

purchased 40 shares in the Louden Canal. The other part of the system has no decree, and the appropriation being a late one the filling of the reservoirs is not assured. It had formerly been the practice to fill the Louden Reservoir more than once during a season, and in 1901 an attempt was made to fill the remainder of the system by means of the decree of the Louden Reservoir and the shares in the Louden Canal, by running water from the latter through the Louden Reservoir; but the Loveland and Greeley Company complained, and an injunction stopped this manner of filling. Lake Loveland can not be filled until after the Louden Reservoir, but, having an earlier right than the rest of the Seven Lakes, it should be filled before they are allowed any water. Had Cemetery Lake been joined to the Seven Lakes the problem would have become still more complicated, for its decree is even older than that of the Louden Reservoir and water could have been run through it into the rest of the Seven Lakes.

Testimony was taken by a referee appointed by the court, and the decision rendered allows the Louden Reservoir to be filled to its decreed capacity of 50,000,000 cubic feet only once each year, and does not allow any water to be run into any part of the Seven Lakes Reservoir on the rights owned by the company in the Louden Canal. The Loveland and Greeley Company claimed that the capacity of the Louden Reservoir was only 25,000,000 cubic feet, but this question was not gone into and the amount given in the original decree was not changed. It also claimed that Lake Loveland had a storage capacity of 600,239,000 cubic feet, or 13,550 acre-feet, and that it should be allowed to carry water through the Barnes Ditch at the rate of 450 cubic feet per second for storing this amount. The Seven Lakes Company claimed that the capacity of the Barnes Ditch was greatly overestimated and that its owner had never run so much through it, allowing water to pass its head gate in the river and go to waste which otherwise might be run into its reservoir. The Loveland and Greeley Company claimed that 450 cubic feet per second had actually been run through the Barnes Ditch.

The Loveland and Greeley Company would rather have had the question in regard to the storage of water on the decree of the canal decided against it, provided the decision in the similar case between it and the Home Supply Company were likewise reversed, for it would gain much more by being allowed to store water in Lake Loveland on the early decree of the Loveland and Greeley Canal.

The Seven Lakes Reservoir is filled partly by seepage and in some years it may receive a supply from the Big Thompson through the Louden Canal, but this will not happen until most of the other reservoirs under the stream have been filled or until a flood fills all the inlets to the reservoirs preceding it.

The company is dependent upon other companies to some extent as

regards both the filling and distribution, having to obtain the use of the Louden Canal for the former and having to pay the Loveland and Greeley Company for carrying the water through its canal. In 1901 the Seven Lakes Company contracted with the Loveland and Greeley Company to carry 56 cubic feet per second to customers under the canal, but on account of the small outlet of the Seven Lakes and the small grade of the outlet ditch the run was commenced with only 40 cubic feet per second and this was gradually diminished to 20 cubic feet per second as the head was lowered in emptying the reservoir. Meanwhile a run was being made from Lake Loveland, and as only 6 feet can be drawn from the Seven Lakes, excepting No. 1, the velocity in the outlet ditch was very low. The deficiency was in a measure made up by the water flowing from Lake Loveland, and the result was that the Seven Lakes Company was paid for the full amount, while a part of it actually came from Lake Loveland. The Seven Lakes Company has insisted that the runs from the two reservoirs be combined for greater economy, but in 1902 the Loveland and Greeley Company refused to comply and charged the Seven Lakes Company $500 for delivering the water. Water was furnished to 55 users and five runs were made. The first and last were failures, but it is claimed that the first was practically used to soak the canal, which was then very dry.

LOVELAND LAKE RESERVOIR.

This reservoir is the property of the Loveland Lake and Ditch Company and was constructed in 1899. The company is a small one, composed of farmers under the lower end of the Handy Ditch, and the reservoir aids the canal in irrigating their lands.

The reservoir was originally a natural lake containing water which came largely from seepage, and in developing it a cut 1,000 feet long was made through the rim of the basin at the south side. This was 20 feet deep at the upper end where the outlet works were placed, and its depth is gradually diminished to that of an ordinary ditch. The outlet was made by laying one line of sewer pipe 36 inches in diameter for a distance of 100 feet in the bottom of the cut and constructing transverse retaining walls of masonry at each end to support the earth filled in on top to the original natural surface of the ground. These walls are 2 feet thick and have wings extending from them along the sides of the cut. The bottom of the ditch just below the outlet pipe is protected as far as the wings extend by an apron of flagging. The gate is of steel, 3 feet square, is brass mounted at the edges, and slides in the grooves of the steel frame. It is placed in a well in the middle of the outlet. The well is 6 feet square on the inside and the walls are 18 inches thick. The well is 25 feet in depth,

5 feet of which is above the ground, probably so that the reservoir may be enlarged by an embankment. The gate stem is a steel rod and the lifting apparatus is of the same pattern as those used at Lake Loveland and the new one at Mariano Reservoir, being a combination of a nut turned by a worm gear and large crank wheel. The apparatus is bolted down to 12 by 12 inch timbers placed across the top of the well.

The area of the reservoir is 160 acres, and when filled 19 feet may be drawn off. It was full in 1901, but was filled to a depth of only 12 feet in 1902, when it was estimated to be two-thirds full. The water surface at this depth is 110 acres.

Its capacity is estimated to be 1,722 acre-feet, and it cost $13,000, or $7.55 per acre-foot. It is now worth $50,000 to the company. It is located 1½ miles northwest of the town of Berthoud, and is just under the Handy Ditch, from which it is filled. Its outlet ditch irrigates 2,000 acres of land on the slope toward the Little Thompson. The Handy Ditch has a capacity of 250 cubic feet per second. After the water stored in the reservoir is run out water is kept running into it during the season, and this being let out at intervals serves to regulate the flow of the Handy Ditch. Before its construction sugar beets and potatoes could not be raised under this part of the Handy Ditch.

The water is measured by the miner's inch method, and in 1902 runs were made as follows: Seventy-two hours, beginning May 25, 100 inches per share; forty-eight hours, beginning June 25, 100 inches per share, and twenty-four hours, beginning July 1, 100 inches per share.

WELCH RESERVOIRS.

This system is private property owned by Mr. C. C. Welch, the president of the Handy Ditch Company. It originally consisted of five natural basins, but when fully developed may be considered as two reservoirs. One reservoir has been constructed by joining together Nos. 1, 2, and 5, all of which are just south of the Handy Ditch, while Nos. 3 and 4, on the north side, which will form the other reservoir, remain as yet unused.

No. 2 is connected with No. 1 on the east side by sewer pipe laid in a tunnel through the narrow natural ridge between them, while No. 5 is connected with No. 1 on the west side by an open cut, and these two are one basin when full. The outlet is at the south side of No. 1 in a cut through the bank 400 feet long, the greatest depth of which is 19 feet. The discharge is controlled by a wooden gate of 2-inch plank at the upper end of a line of iron pipe 3 feet in diameter. The gate has a wooden stem and is raised by a screw. The capacity of the basin could be greatly enlarged by constructing an embankment along the south side of the basin.

The combined areas of Nos. 1, 2, and 5 is 208 acres, and they hold 2,948 acre-feet, besides some unavailable water. Their cost was very small. The reservoir has been full every year since its construction, except 1902, when only 8 feet of water was stored. The reservoir holds twice this depth. It has no decree, but by virtue of rights in the Handy Ditch some water is run into it and used as it is convenient. A contract exists between its owner and the Handy Ditch Company relative to running water into the reservoir. Water is turned from the Handy Ditch immediately into Nos. 1 and 2 through inlet gates at each. The water is distributed through the outlet ditch of the reservoir, which is high enough to cover most of the lands south of the Handy Ditch. The reservoirs of this system could be conveniently connected with Loveland Lake Reservoir, since they are operated in the same manner.

Nos. 3 and 4 are higher than the others, and surveys were made in the fall of 1902 for the development of these. They will be one basin when full. The proposed plans call for an embankment at the south and west sides, the greatest height of which will be 14 feet. This will give an area of 260 acres and a capacity of 3,212 acre-feet with an additional 39 acres of unavailable water 11 feet deep in the lowest portion of No. 3.

The Handy Ditch Company has long felt the need of storage facilities in connection with its system, and since these basins are above the lands of nearly three-fourths of the users under the ditch there is a probability of their transfer to the company. The Handy Ditch and the Home Supply Canal run nearly parallel throughout, the ditch being the higher and irrigating land on the Little Thompson slope, while the canal irrigates lands on both slopes. The lands under them are practically the same in character. The ditch is entitled to 172.43 cubic feet per second from the river before the canal can divert any water. Both have been reenforced by the purchase and transfer of rights in the older and smaller lower ditches on the river having excessive appropriations, but in both cases the use of water under these purchased rights has been limited as a result of litigation instigated by irrigation interest on the north side of the river, and the advantages gained by the two will nearly balance. The Home Supply system is, however, much the better equipped—a condition which exists solely on account of its efficient storage system. The Handy Company is unfortunate in not having suitable reservoir sites, those proposed being too small to aid materially in serving the entire ditch. The deficiency is made up in part by the many small private reservoirs under the ditch. The advantage possessed by the irrigators owning these is that they can store the water they receive from their ditch rights and hold it for late irrigation or use it at their convenience.

BIG CUT RESERVOIR.

The Loveland and Greeley Canal toward the lower end gains the top of the divide between Big Thompson and Cache la Poudre rivers and irrigates land on both slopes, several of the largest laterals being taken from it on the north side. At one point farther up in its course it almost reaches the top, and here a deep cut was made, through which the Big Cut or Oklahoma Lateral was taken to irrigate lands in the Oklahoma Draw, draining to the Cache la Poudre. Irrigators in this little valley have incorporated the Big Cut Lateral and Reservoir Company and constructed their reservoir, which is filled from the Big Thompson by the canal and lateral. The reservoir is on the west side of the draw and supplies land on that side, while the lateral covers the land on the east side.

The reservoir is 76 acres in area and holds 1,142 acre-feet of water.

LAWN RESERVOIR.

The Lawn Reservoir is owned by the Farmer's Irrigating Ditch and Reservoir Company. The company's canal is the Farmer's Irrigating Canal, which leaves the Big Thompson on the north side at the town of Loveland. The reservoir is located in secs. 24 and 25, T. 6 N.,

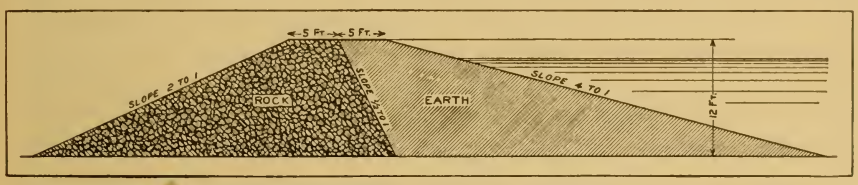


FIG. 9.—Cross section of dam of Lawn Reservoir.

R. 74 W., and is in the mountains 30 miles west of Loveland. It is filled by natural drainage to Fall River, a tributary of the Big Thompson, and the water stored is turned into the river, to be diverted at the head gate of the Farmer's Irrigating Canal below. The basin is a natural one, into which runs a small stream. A cut was made for the outlet works. The reservoir was only partly completed in 1902, but 12 feet of water was drawn off. The capacity will be enlarged by a dam which will be completed before the spring of 1903. The plans prepared by the company's engineer propose a dam 12 feet high, but it may be finally decided to reduce this to 6 feet. The dam will be constructed of loose rock on the lower side and of earth on the upper (fig. 9). The rock portion will be 5 feet wide on top and will have a slope of 2 to 1 on the outside and $\frac{1}{2}$ to 1 on the inside. The earth filling against the latter will add 5 feet to the width of the top of the dam which will be given a slope of 4 to 1 on the inside.

The outlet is through a steel pipe 3 feet in diameter and three-sixteenths of an inch in thickness. It is covered by 3 inches of concrete

and has three concrete collars 1 foot thick. The regulating gate will be an iron water valve which will be placed in a well at the middle of the dam. The walls of the well are founded on 2 feet of concrete and for 3 feet in height are of masonry 1 foot thick. Above this the well is cased with wood.

In 1902, 25 cubic feet per second was drawn from the reservoir for twenty days, which gives a total of 992 acre-feet. When the reservoir is completed the capacity will be much greater. There are 30 shares in the Farmer's Irrigating Company; therefore 33 acre-feet was stored for each share, although the amount actually furnished was less, since some loss must occur in running the water so far to the land. Each share represents a 160-acre water right. The reservoir will cost not over $12,000, or $12.10 per acre-foot. The shares were worth $1,200 each in 1901, but since the construction of the reservoir they are worth $2,000 each.

LITTLE THOMPSON RESERVOIR.

The Little Thompson Reservoir is on the line of the Hillsborough Canal, 3½ miles above its end. It is owned by the Little Thompson Reservoir and Water Supply Company, an organization composed of the farmers under this part of the canal. The embankment was constructed in 1897 and belongs to a very expensive class. An embankment was constructed across a gulch or draw which is very large compared with the basin above it. The greatest height of the embankment is 34 feet and its length 860 feet. There is a slight bend at one point. It is 20 feet wide on top and its slopes are 1½ to 1 on the outside and 5 to 1 on the inside. It was constructed in 3-foot layers and is not riprapped.

The outlet is at the base of the embankment, and was made by laying two lines of 21-inch cement pipe in a bed of concrete 6 inches deep and 6 feet wide. Cement collars were placed around the pipes at each joint. The retaining walls at the ends are of vitrified brick set 4 feet into the earth and having 6 feet of height above. The gate well protrudes from the inner slope of the embankment near the top and is founded on 2 feet of cement. The well is of vitrified brick, and the gates are of wood, faced with steel plates at the edges. They slide on a frame of 12 by 12 inch timbers built against the inside of the well. The gate rods are 34 feet long, and, being only 1½ inch in diameter, it was found necessary to brace them every 2 feet to prevent their springing when the gates were being forced down. The power is applied by means of nuts on the rods. The reservoir is in the bluffs along the south side of the Little Thompson near its junction with the Big Thompson, and when floods occur water rushes down the gulches at a rapid rate, so for the protection of the dam a waste way

was cut in the natural earth around one end of it. The dam was constructed on the old embankment of the Hillsborough Canal, which was 15 feet high where it crossed the draw. The owners of the reservoir have realized since that they made a serious mistake in leaving a distinct seam between the old embankment of the ditch and the new earth of the dam. The new portion of the dam became saturated with seepage, causing it to break away to within 2 inches of the water's edge in June, 1900, when there was 29 feet of water against the dam. If the old embankment had been plowed and worked in with the fresh earth the break would probably not have occurred. Rock and gravel were used as a solid foundation in repairing the break.

The reservoir covers 160 acres and holds 987 acre-feet. It cost $18,000, which gives the unusually high figure of $18.24 per acre-foot. The expense of maintenance is $600 annually. The stock of the company consists of 120 shares, which have advanced in value from $90 to $200 each. The reservoir holds 8.23 acre-feet per share. Prior to 1897, every farm, without exception, under the Hillsborough Canal below the reservoir that had been dependent upon the canal alone went to foreclosure and could not be made to produce the owners' expense of maintenance. In 1898 the best land, with its water rights, could be bought for from $12 to $15 per acre, while it is now selling at $60 per acre as a result of the construction of the reservoir.

The reservoir receives water from both Big and Little Thompson rivers through the Hillsborough Canal, which heads in the former and crosses the latter. The main part of the canal is above this crossing, where its capacity is 160 cubic feet per second. The part below the crossing, known as the Little Thompson Ditch, has a capacity of 150 cubic feet per second as far as the reservoir. The ditch runs through the reservoir, and it is stated that the water coming to it will fill it four times each year. The Little Thompson furnishes about 40 cubic feet per second to the inlet during April, and from 10 to 15 cubic feet per second during June, July, and August. Its flow in these last few months is made up almost entirely from seepage, and it is claimed that it was practically dry fifteen years ago. The reservoir has no decreed right for filling.

The reservoir is only 3½ miles above the lower end of the Hillsborough Canal, and it is the only one used in connection with it. Those irrigators under the canal below the reservoir can not depend wholly on the reservoir, but the canal would be of little benefit to them without it. The water is measured in its distribution over trapezoidal weirs. In 1902 the amount stored was only 528 acre-feet, but 987 acre-feet was run in afterwards and used.

ISH LAKE RESERVOIR.

The reservoir of the Boulder and Larimer County Irrigation and Manufacturing Company is commonly called Ish Lake. It is on the south side of the Little Thompson, and is directly on the line between Boulder and Larimer counties.

The reservoir is 280 acres in area and is 20 feet deep. Its capacity is estimated at 1,722 acre-feet. An embankment 600 feet in length and 15 feet high was constructed along the north side, and it is well riprapped. It is 15 feet wide on top and has slopes of 2½ to 1 on the inside and 1½ to 1 on the outside. The outlet is through a 24-inch cement and gravel pipe laid in a cut and is under the embankment. The pipe is surrounded by a transverse masonry wall at each end. It extends some distance into the basin beyond the embankment and drains water below the level of the base of the embankment. The gate is operated in a masonry well placed at the inner edge of the top of the embankment. The well is round and is 6 feet in diameter. The gate is of oak and is raised by a nut on the gate rod.

The supply for filling the reservoir is received through its inlet ditch from the Little Thompson. Two decrees have been given to the Boulder and Larimer County Irrigation and Manufacturing Company's Ditch and Reservoir—one dated June 30, 1875, for 27.20 cubic feet per second, one dated May 20, 1877, for 39.52 cubic feet per second. The water is used below it on the lands of the owners in the Little Thompson Valley. This stream furnishes very little water for storage, and, unlike the Little Thompson Reservoir, Ish Lake is too far up to benefit much by the seepage into the stream. It has been a great benefit to these lands, however, and paid for itself in a short time. In 1901 it was full, but in 1902 there were no floods in the Big Thompson and practically no water was caught. Four feet of water remained in the lowest portion of the basin below the level of the outlet, and in an attempt to save as much as possible of the crops dependent upon the reservoir all this otherwise unavailable water was pumped into the outlet ditch by means of a small pump and portable steam engine.

OTHER RESERVOIRS ON THE BIG THOMPSON.

Many of the small reservoirs are filled partly or wholly by seepage. Some are distinctly seepage reservoirs, having been filed upon as such under the laws of the State, which make seepage water subject to the same laws as the water of natural streams. Many of them are filled partly or wholly from some of the large canals, and, following strictly the laws of the State, this use is often illegal, for the storage of water when it is needed for direct irrigation is prohibited. The view that the farmers themselves take is that they are entitled to a certain amount of water by the ownership of stock in a ditch company, and

that when this water is measured out to them at the head of a lateral they have a right to use it as they please. When a run is made in the canal they often store the water in their small reservoirs and hold it for late irrigation. Some of these reservoirs act as regulators to the laterals and water is kept running through them most of the season. Sometimes water is stored in the reservoir during the night and used from it during the day, thus greatly increasing the efficiency of the water supply. When there is a flood in the streams and all the large inlets are full, water is taken by the large canals, from which it is turned into the small reservoirs. Sometimes this is done in the spring, and after the reservoirs are emptied they are again filled as previously described. It is evident that this is an economical use of water, and since others are not injured no objections are made to the practice.

No filings were ever made for many of even those reservoirs which were constructed while filings were required by law. The sites of others were filed upon so many times before final construction that the records are very confusing. The reservoirs are usually constructed by the farmers themselves and are nearly always situated on their owners' farms. They are usually used in irrigating one or two farms, seldom for three. It is noticeable that they are grouped under those canals not supplemented by large storage systems. On the Big Thompson most of them are under the Handy Ditch and the Louden Canal, neither of which is fortunate in having suitable sites for large reservoirs. Practically no small reservoirs are found under the Home Supply Canal, which has an efficient storage system.

There are a great many small reservoirs under the Cache la Poudre as well as under the Big Thompson, but no attempt was made to collect data regarding them. Those under the Big Thompson have been used to illustrate the extent of the usefulness of small reservoirs and the list for the stream is fairly complete. While none of those described is of any great importance, considered singly, in the aggregate they are no small factor in the maturing of the late crops.

In regard to the cost of small reservoirs, it is impossible to secure accurate data, for they are usually constructed by the farmers themselves and no account is kept of the work.

The Rist Reservoir is the only one taking water directly from the river. Nearly all others are filled from one of the large canals.

RIST RESERVOIR.

This reservoir, although small, is one of the oldest in the valley. Together with the George Rist Ditch, it was constructed to supply water for the irrigation of the Rist ranch, to which both belong. This property is now known as the Buckingham estate, and consists of 1,800 acres, divided into farms which are leased, the water being prorated among the several tenants according to a paragraph in the leases.

The reservoir has priority No. 1 for filling, its decree, dated September 15, 1874, being for 5,210,865 cubic feet. This gives 120 acre-feet as its capacity. It is filled from the Big Thompson through the George Rist Ditch, which was enlarged by the Home Supply Company when the site for the Mariano Reservoir and the right of way was purchased, and has been since maintained by the latter company. The reservoir is 27 acres in area, and the water is drawn off through an open ditch, where the discharge is controlled by a wooden head gate.

RESERVOIRS FILLED FROM HANDY DITCH.

HUMMEL RESERVOIR.

This reservoir is located on the line between secs. 8 and 17, T. 4 N., R. 68 W., and was constructed in 1882. It covers 35 acres and holds 12,807,000 cubic feet, or 294 acre-feet, which is the amount of its claim, filed in 1882. Ten feet of water may be drawn off, while 6 feet is unavailable. It irrigates 400 acres of land belonging to its owner, Mr. J. C. Hummel. It was filled in 1901, but only partially filled the following year, which is the second time a shortage has occurred. In 1902 the water was used on 112 acres of wheat, 18 acres of oats, 15 acres of alfalfa, and 20 acres of sugar beets. It is filled in the spring, there being a contract for this purpose between its owner and the ditch company. The embankment of the reservoir is 12 feet high and the outlet is of 14-inch tiling. The gate is of wood and is operated in a masonry well.

DE FRANCE RESERVOIR.

This reservoir is located about the common corner of secs. 4, 5, 8, and 9, T. 4 N., R. 68 W., and covers 32 acres. Its capacity is the amount claimed in 1883, 12,000,000 cubic feet, or 275 acre-feet, and it irrigates 250 acres of the land of its owner, Judge A. H. DeFrance. It was constructed in 1883, and was used that year and has been used every year since. It is filled in the spring, and by contract its owner pays the ditch company a consideration for this. The embankment is 10 feet high and the outlet is of tiling.

BEASLEY RESERVOIR.

This reservoir was filed on in 1881, and is now owned by J. Y. Munson. It is locally known as Town Lake, or Berthoud Lake, because it supplies water used in the town of Berthoud, 1½ miles south of it. Its appropriation under date of 1881 was originally for 8,000,000 cubic feet. It is located in sec. 11, T. 4 N., R. 69 W., and covers 40 acres. It has a small embankment, which is riprapped with stone. Its outlet is of wood, the gate being at the upper end, in the reservoir. It repaid its cost in two years and irrigates 320 acres.

WELCH LAKE RESERVOIR.

This reservoir is located in the SE. ¼ of sec. 35, T. 5 N., R. 69 W. It is just above the Home Supply Canal, the embankment of the reservoir, 10 feet high, being along the south bank of the canal. It is filled to some extent by seepage as well as from the Handy Ditch. The outlet is a tube extending through the embankment, made of four 2 by 12 inch planks nailed together, and having a wooden gate. The reservoir is below the lands of its owners and its supply is used in an exchange with the Home Supply Canal, into which it is run. It is 23 acres in area and has a claimed supply of 676 acre-feet, although it irrigates only 80 acres.

HUPP LAKE RESERVOIR.

This reservoir is situated in the NW. ¼ of sec. 35, T. 5 N., R. 69 W. It is 15 acres in area and holds 50 acre-feet, partly irrigating 160 acres of the lands of its owners. It has a small embankment, and the outlet is through an open cut, where a head gate controls the discharge.

SMITH-WELTY RESERVOIR.

This reservoir is located in sec. 15, T. 4 N., R. 68 W. Its embankment is 6 feet high, and it covers 25 acres. Its capacity is 4,356,000 cubic feet, or 100 acre-feet, and it is used in the irrigation of the lands of its owners, for whom it is named.

FAGAN RESERVOIR.

This small reservoir irrigates probably 40 acres. It is located in the SW. ¼ of sec. 11, T. 4 N., R. 69 W.

VOGL RESERVOIR.

This reservoir is in the SW. ¼ of sec. 11, T. 4 N., R. 69 W., and supplies water for probably 40 acres. The outlet consists of a wooden head gate in an open ditch.

M'COY RESERVOIR.

This reservoir was first used in 1902. It is located in the SE. ¼ of sec. 11, T. 4 N., R. 69 W. It furnishes water for one small farm and is very small.

JANSEN RESERVOIR.

The reservoir owned by James Jansen is also known as the Cole Reservoir, and appears in the articles filed in the office of the county clerk as the reservoir of the Sunny Slope Reservoir Company. It covers 40 acres and is located in the center of sec. 12, T. 4 N., R. 69 W., under the Handy Ditch, but it is filled entirely from seepage. Its capacity is probably 4,356,000 cubic feet, or 100 acre-feet, and it has recently been unused for irrigation.

WILSON RESERVOIR.

This reservoir is the private property of S. J. Wilson and is used in connection with his land. It is filled from the Zweck Lateral of the Handy Ditch and holds 6,511,000 cubic feet, or 149 acre-feet, which was the amount filed on in 1891. Its embankment is 8 feet high and 300 feet long. The outlet is a wooden conduit with the gate at the upper end controlled from a platform. It is located in sec. 20, T. 4 N., R. 69 W.

WILSON-STREVER RESERVOIR.

This reservoir is located in the SE. ¼ of sec. 17, T. 4 N., R. 69 W. The embankment is 6 feet high, making the water surface cover 31 acres. It is filled through the Zweck Lateral of the Handy Ditch and irrigates 100 acres. The outlet is a wooden conduit with the gate at the upper end. The capacity is estimated to be 100 acre-feet.

LOVELAND LATERAL RESERVOIR.

This reservoir is sometimes confused with the reservoir of the Loveland Lake and Ditch Company about 3 miles east of it. It is located in the NW. ¼ of sec. 21, T. 4 N., R. 69 W., and is filled from the Handy Ditch through the Zweck lateral. Its appropriation made in 1902 is for 630 acre-feet, and this may be taken as its capacity, although it could be largely increased by an embankment 10 feet high. At present the water is drawn from the basin through a cut in which a wooden head gate controls the discharge.

KEE RESERVOIR.

This reservoir is located on the line between secs. 17 and 20, T. 4 N., R. 69 W., and is about 10 acres in area. The embankment is 12 feet high and extends across a small draw. The reservoir is filled from the Handy Ditch by the Zweck Lateral, and serves to irrigate about 50 acres. Its capacity is estimated at 100 acre-feet.

HUPPE RESERVOIR.

This reservoir was constructed and is owned by Huppe Brothers, and is situated on their land in the NW. ¼ of sec. 28, T. 4 N., R. 69 W. It is filled from the Zweck Lateral of the Handy Ditch, and recently has not been used to advantage, as it has swamped 20 acres of land with alkali, and that is as much as it will irrigate. Its papers were filed in 1882, claiming 3,169,000 cubic feet, or 73 acre-feet, which is at least not under its capacity. It has an embankment 4 feet high and covers about 10 acres.

RESERVOIRS FILLED FROM LOUDEN CANAL.

FAIRPORT LAKE RESERVOIR.

This reservoir, commonly called Fairport Lake, was formerly known as Geneva Lake, and was filed upon once under that name. It is located in sec. 13, T. 6 N., R. 69 W., and is 53 acres in area. At present its embankment is high enough to allow 12 feet of water to be drawn off, but its capacity could be increased to 50,000,000 cubic feet or more by increasing the height of the embankment. Its present capacity is 25,473,000 cubic feet, or 585 acre-feet, this being the amount claimed in 1883 by the Fairport Lake and Canal Company. It is filled from the northern extension of the Louden Canal and irrigates 1,500 acres. The canal, like the Handy Ditch, is badly in need of storage works, and the enlargement of this reservoir has been considered by the company, which has no good available sites.

BIG THOMPSON RESERVOIR.

This reservoir, much better known as Cemetery Lake, is one of the oldest reservoirs in the Big Thompson Valley. It supplies water for the irrigation of 400 acres, and is owned by F. G. Bartholf and others. The reservoir has priority No. 4 on the Big Thompson, entitling it to 44,000,000 cubic feet from that stream, under date of May 18, 1881. It is probable that the capacity of the reservoir is equal to only about one-half this amount, or 500 acre-feet. It is filled through the Louden Canal, and is located north of the town of Loveland, between Lake Loveland and the Seven Lakes Reservoir. The basin is entirely natural and the water is drawn off through a cut. A head gate in the latter controls the run off.

By reason of its excessive decree it, like the Louden Reservoir and the old ditches, has been regarded as desirable property, and an attempt was made in 1901 by the Seven Lakes Company to include it in the Seven Lakes Reservoir system as No. 5. Had the transfer been effected it is probable that the amount decreed, and not the amount actually held by the reservoir, would have been taken from the river and the excess run through Cemetery Lake into the rest of the Seven Lakes reservoirs.

NELSON RESERVOIRS NOS. 1 AND 2.

These reservoirs are used together and are owned by John H. Nelson and others, they having filed a claim of an appropriation of 7,970,000 cubic feet, or 1,830 acre-feet, in 1902. They cost about $100 and supply water to 214 acres. They are filled from the Louden Canal and floods.

BENSON RESERVOIR.

This reservoir is owned by Mr. A. S. Benson, president of the Louden Irrigating Canal Company. It is located in sec. 10, T. 5 N., R. 69 W., and covers 13 acres. It is filled from the Louden Canal and is used to regulate the flow of one lateral. Its owner claims that the flow of the ditch is practically doubled as the water is turned into the reservoir at night and then used from it during the day. The embankment is 4 feet high, but 5 feet of water can be drawn off.

BENTAL RESERVOIR.

This reservoir is in sec. 2, T. 5 N., R. 69 W., and is filled from the Louden Canal. It covers 10 acres and supplies water for the irrigation of 60 acres.

DARROUGH RESERVOIR.

This reservoir is located in sec. 4, T. 5 N., R. 68 W., and covers 60 acres. An appropriation was claimed in 1891 for 18,060,000 cubic feet, or 415 acre-feet.

RESERVOIRS FILLED FROM LOVELAND AND GREELEY CANAL.

DAWKINS RESERVOIR.

This reservoir is located in secs. 21 and 28, T. 5 N., R. 67 W. Its owners claim a capacity of 1,106,000 cubic feet, or 25 acre-feet. It is filled by seepage from lands under the Loveland and Greeley Canal.

STEELE & PHILLIPS RESERVOIR.

This reservoir is owned by Robert Steele and J. B. Phillips and is in sec. 16, T. 5 N., R. 66 W. Its area is 10 acres, and its owners claimed an appropriation of 1,600,000 cubic feet, or 37 acre-feet, in 1889. It is filled at intervals during each season from the Loveland and Greeley Canal and acts as a regulator in irrigating the two farms of its owners. The reservoir cost $300.

SHEEP DRAW RESERVOIR.

This very small reservoir is filled by seepage from the land under the Loveland and Greeley Canal. It was formed by constructing a small embankment across a gulch.

BARTEL RESERVOIR.

Bartel Brothers own this reservoir, which is located in sec. 20, T. 5 N., R. 65 W. It is very small and is filled mainly from seepage from lands irrigated by the Loveland and Greeley Canal. It has a small embankment across a gulch, which broke at one time and was rebuilt.

RESERVOIRS FILLED FROM HOME SUPPLY CANAL.

SHAY RESERVOIR.

This reservoir is located in sec. 3, T. 4 N., R. 68 W., and is filled from the Home Supply Canal. It is used in irrigating one farm only.

CHAPMAN RESERVOIR.

This reservoir is located in sec. 6, T. 4 N., R. 68 W., and is between the Home Supply Canal and the Home Supply Reservoir Ditch. It is very small.

RESERVOIRS ALONG THE LITTLE THOMPSON.

WHITE-BUTLER RESERVOIR.

This reservoir was constructed in 1901 and is located in secs. 22 and 27, T. 4 N., R. 68 W. It was formed by a dam across a draw in the bluffs along the south side of the Little Thompson and is filled mainly by floods, but may be filled from the Highland Ditch from the St. Vrain Creek. The water is used on the land of its owners, E. White and T. Butler, along the Little Thompson. The dam is 23 feet high, 440 feet long, and 12 feet wide on top, and has outside slopes of 1½ to 1 and 4 to 1, respectively. The outlet works are built of Oregon fir, there being a tube through the dam and a well in the middle, where the gate is placed. The cost was $1,400. Sixteen feet of water can be drawn from 18 acres. The amount claimed in 1897 was 8,146,000 cubic feet, or 187 acre-feet, The cost per acre-foot would therefore be $7.49.

CULVER RESERVOIR.

This reservoir is filled from the Little Thompson and is in sec. 31, T. 4 N., R. 69 W. It is about 20 acres in area and has a small rip-rapped embankment.

KNAUS RESERVOIR.

At present this reservoir has a low embankment and a small wooden head gate in an open ditch, which holds some water, but its capacity could be greatly increased by a higher embankment. It is situated just outside the foothills, and the greatest objection to its enlargement is the difficulty of filling it. The natural drainage would not be sufficient, and it would require an inlet ditch. One could probably be made from the Little Thompson, but it would be difficult and expensive, and it is a question whether its construction would be warranted, since that stream furnishes so little unappropriated water for storage.

Nothing was learned of Bennetts Reservoir, which is decreed the third right on Big Thompson River, except that it is probably on the south side of Little Thompson River. According to the decree its capacity is only 29 acre-feet.

The Rockwell Reservoir and Baxter Reservoir are on the south side of the Little Thompson, but they are filled from the St. Vrain Creek.

PROPOSED WORKS

BOYD LAKE SITE.

The Boyd Lake site has been under consideration ever since the practicability and value of reservoirs in north-central Colorado have been clearly demonstrated, but as yet nothing has been accomplished toward its construction. Meanwhile so many storage works have been developed that the available supply for filling Boyd Lake is coming to be seriously questioned. It is probable, however, that it could be used to an advantage in some years, and if so it would repay its cost in a few such seasons. Its location gives it one unusual advantage, the possibility of storing in it the surplus waters of both the Cache la Poudre and Big Thompson rivers, which may be accomplished by an extension of the New Mercer Canal from the former stream and of the Barnes Ditch from the latter, although both should be enlarged in order to insure the carriage of flood waters.

The site really consists of two natural lakes, Boyd Lake and South Lake, which would become one body of water when the large basin including both is filled. A survey of the site was made in 1897 by Capt. H. M. Chittenden, of the United States Corps of Engineers, and is described as the Loveland site in his report on "Reservoir Sites in Wyoming and Colorado." The area of the basin was found to be 1,920 acres and its capacity above the present level of the water surface in the lower lake, this being the elevation of the proposed outlet, was determined to be 45,740 acre-feet. The outlet works recommended were elaborate and the cost was estimated at $262,106, or $5.73 per acre-foot, which is very reasonable. The cost would be greatly lessened and a large capacity would still be secured if the basin were not drained so low as the plans provide, and it is thought by many that this would be the more feasible plan. The basin can be drained most conveniently to the Cache la Poudre Valley by a cut through the rim of the basin at the northeast side of Boyd Lake.

In 1893 the Northern Water Storage Company filed a claim for 1,143,450,000 cubic feet, or 26,250 acre-feet, for a reservoir at the Boyd Lake site. The Boyd Lake Reservoir Company filed another in 1895 for 1,305,972,360 cubic feet, or 29,981 acre-feet. Two other filings were made in 1902, one by the Seven Lakes Reservoir Company for 2,340,300,000 cubic feet, or 53,726 acre-feet, and one by the Boyd Lake Irrigation Company for 1,623,045,000 cubic feet, or 37,259 acre-feet. The Seven Lakes Company proposes to connect the Seven Lakes Reservoir with Boyd Lake by making an outlet at the dam across Dry Creek at No. 2 of the Seven Lakes. They have also desired to connect Seven Lakes with Lake Loveland and to enlarge and extend the Barnes Ditch to the Seven Lakes, making it the outlet of the system. This plan of cooperation was always opposed by the Loveland and Greeley Company, and one reason for the farmers buying out the company's interest was to facilitate operations.

The other parties who filed on the Boyd Lake site in 1902 made surveys of the basin, but whether any further progress will be made by them in the construction of the reservoir is doubtful. Of the four filings on record for this site all the amounts claimed have been less than the capacity of the basin, as shown by the Corps of Engineers, save that of the Seven Lakes Company, which, even including the Seven Lakes, is far in excess of the amount that can be stored.

WILLOW PARK SITE.

A reservoir site in secs. 31, 32, and 33, T. 5 N., R. 73 W., and secs. 4, 5, and 6, T. 4 N., R. 73 W., is in point of size almost as important as the Boyd Lake site. This is the Willow Park site and embraces a part of a large basin in the mountains at the head waters of the Big Thompson, which is known as Willow Park, and is at the upper end of Estes Park. One of the principal tributaries of the South and main Fork of the Big Thompson runs through this basin, receiving its supply from the snows on the Continental Divide near Longs Peak. The dam site is at the lower end of this basin where the canyon narrows, and here a masonry dam of almost any reasonable height could be constructed.

A claim was filed in 1893 by the Willow Park Reservoir Company for 1,546,032,000 cubic feet, or 35,492 acre-feet. It was proposed to make the dam 100 feet high and about 300 feet long, which would make the water surface cover an area estimated at 987 acres. The plan was not considered advisable with the price of stored water at that time, but it would probably be a paying investment at the present price.

FOUR LAKES SITE.

The Horseshoe Park Reservoir and Fishing Company in 1896 filed a claim for 279,951,000 cubic feet of water to fill reservoirs numbered from 1 to 5 inclusive, in secs. 13, 14, and 24, T. 5 N., R. 73 W., the aggregate area being 164 acres. These were to be in Estes Park, in the mountains, at the head waters of the Big Thompson. They were not constructed, and in 1899 the Four Lakes Reservoir Company filed a claim for water for four of these sites. The areas and capacities given for the same basins were practically the same as in the former claim, and were as follows:

Capacities of Four Lakes Reservoir sites.

Site.	Area.	Capacity.	
	Acres.	*Cubic feet.*	*Acre-feet.*
No. 1	13	9,000,000	207
No. 2	20	24,000,000	551
No. 3	9	15,000,000	344
No. 4	81	200,000,000	4,591
Total	123	248,000,000	5,693

No. 1 in this statement was the No. 2 of the former, No. 1 of the former filing not being included in this filing. As yet only a small dam has been constructed, which forms a lake for fishing purposes. It was proposed to construct a masonry dam 96 feet high in a canyon where it was only 60 feet wide.

MUD LAKE SITE.

A natural lake, known as Mud Lake, at the west common corner of secs. 7 and 18, T. 4 N., R. 69 W., has been considered with a view to making it supplement the flow of the Handy Ditch. The objections to its development are that it is small and that its filling could not be depended upon. The site is just outside the foothills, and at one time other parties constructed an inlet ditch one-quarter mile long from Dry Creek, a tributary of the Little Thompson. A curved masonry dam 15 feet high, carelessly constructed, extends across the channel at the point of diversion. The stream is dry most of the time, but floods occur occasionally and the channel back of the dam has been filled in with sand. The floods are so uncertain that seasons pass without any, and they are of so short a duration that the ditch would have to be enlarged to be of any service.

The basin would require no embankment and a survey has shown that by cutting through the bank 30 feet of water covering 75 acres could be drawn off and run into the Handy Ditch.

OTHER PROPOSED SITES.

A claim was filed in 1899 by the Bear Lake Reservoir Company for 2,356,576 cubic feet or 54 acre-feet for a reservoir to be constructed in the mountains at the headwaters of the Big Thompson in T. 4 N., R. 74 W. This site was never developed. Another site for a mountain reservoir is at the junction of the North and South Forks of the Big Thompson.

Two natural lakes, one in sec. 13, T. 4 N., R., 69 W., and the other in sec. 18, T. 4 N., R. 68 W., might be used for storage by running water into them from the Handy Ditch, but there are some objections to their development. Both would require cuts 20 feet deep for some distance to drain the water, probably a rather expensive work for the amount of water they would hold, and they are situated too low to cover any land under the Handy Ditch. The water could be used on land along the Little Thompson east of them. At present each basin contains about 10 feet of seepage water covering 40 acres and each could be filled to twice that depth, when the water would cover 100 acres more.

A claim was filed in 1894 for 1,350,000 cubic feet or 31 acre-feet for the Big Hollow Reservoir in sec. 27, T. 5 N., R. 68 W., and one in 1898 for 3,500,000 cubic feet or 80 acre-feet for the Allen Reservoir in sec. 6, T. 4 N., R. 67 W. Both of these sites are in draws in the Big

Thompson drainage area and, requiring dams, would be expensive compared with their usefulness. It is not probable that they will ever be developed.

A claim was filed in 1891 for the Basch Reservoir in sec. 10, T. 5 N., R. 68 W., for 1,469,000 cubic feet or 34 acre-feet. The reservoir has not been constructed, and as the site is in a draw it is not a good one.

A site in secs. 9 and 10, T. 5 N., R. 69 W., on land owned by A. S. Benson and A. Rist, could be used for filling from the Louden Canal. The site was surveyed in 1901, and it was determined that by constructing a small embankment 15 feet of water covering 77 acres could be stored.

The Sanborn Reservoir sites Nos. 1 and 2 are in secs. 13 and 14, T. 5 N., R. 66 W. A claim for No. 1 of 9,104,000 cubic feet or 209 acre-feet, covering 25 acres, and one for No. 2 for 13,068,000 cubic feet or 300 acre-feet, covering 30 acres, was made in 1898. No work has been done at No. 1, and the embankment at No. 2 was not completed. It was proposed to pipe water from No. 2 to the town of Greeley for domestic purposes, since the reservoir, being on the bluffs, would give the necessary pressure. It would be filled from the Loveland and Greeley Canal and by seepage.

A site in sec. 2, T. 5 N., R. 69 W., owned by George W. Alford, could be used by constructing a small embankment and filling the basin from the Louden Ditch.

Other small sites which have been filed on but have apparently not been developed and used are as follows: Humphreys Reservoir, in sec. 33, T. 6 N., R. 69 W.; Taylor and Case Reservoir, in sec. 26, T. 5 N., R. 69 W.; Finch Reservoir, in secs. 27 and 28, T. 5 N., R. 68 W.; Samuels Reservoir, in secs. 35 and 36, T. 5 N., R. 68 W.; Nix Reservoir, in sec. 1, T. 4 N., R. 69 W., and sec. 6, T. 4 N., R. 68 W., and Goodwin Reservoir, in sec. 3, T. 4 N., R. 69 W.

CONSTRUCTION WORK.

In few places are there as many natural reservoir sites as on the plains between the mountains and South Platte River in northern Colorado. These sites are natural depressions, which have bottoms almost impervious to water, indicating that at one time they held water. Many of these basins require embankments on one or more sides, but others require none, and all that is necessary is a cut through the natural rim in which to build outlet works with controlling gates. The Lone Tree and Long Pond reservoirs, already described, belong to this type. The Fossil Creek and Cache la Poudre reservoirs are representatives of those where the whole depth of water impounded is due to an embankment, while those which require both cuts and embankments are exemplified in the Larimer and Weld and Windsor reservoirs. Fig. 10 shows cross sections through the embankments and outlets of a number of the reservoirs examined.

The most practicable height for dams in the canyons of mountain streams must be determined from various conditions. The unappropriated supply available for storage may or may not all be required, although in this locality the entire flow of the streams can be profitably utilized when stored so that it can be used at the proper times. The capacity of a reservoir probably never varies directly with the height of the dam, since the surface increases in area as its level is raised. The cost may not vary directly with the capacity of the reservoir, and must be considered relative to the value of the stored water, which changes from time to time, although it seldom decreases. The height

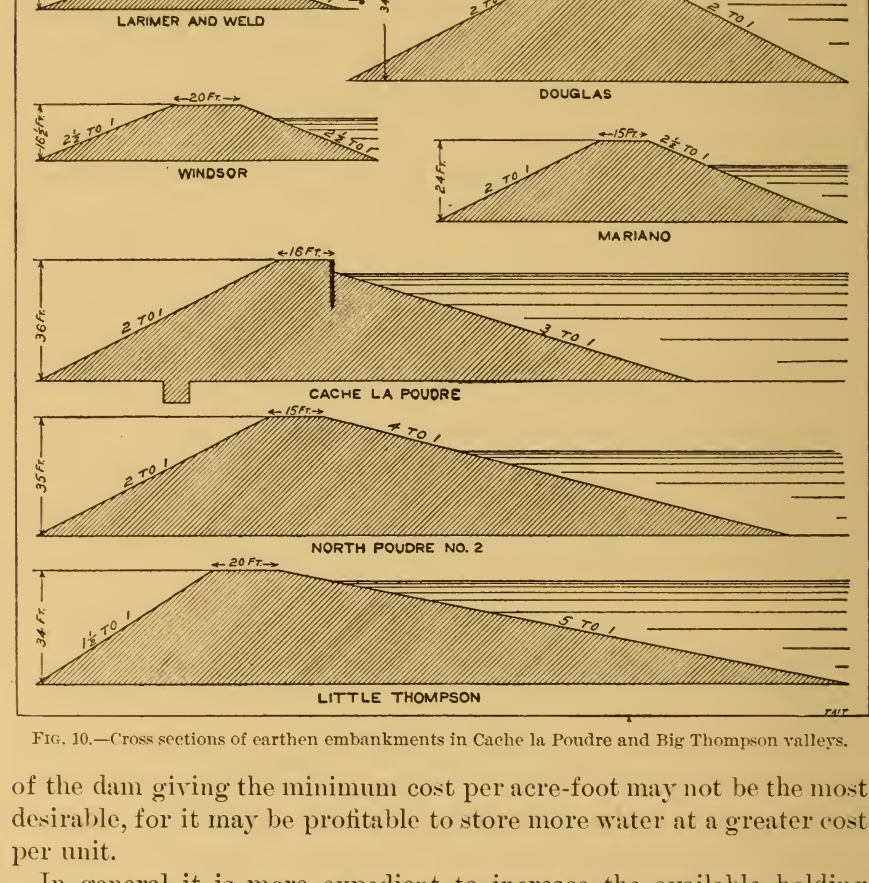


FIG. 10.—Cross sections of earthen embankments in Cache la Poudre and Big Thompson valleys.

of the dam giving the minimum cost per acre-foot may not be the most desirable, for it may be profitable to store more water at a greater cost per unit.

In general it is more expedient to increase the available holding capacity of basins by embankments than by deep cuts for the outlets, because a certain increase in depth at a high contour gives a much greater increase in capacity than the same depth at a low contour, on account of the great difference in the two areas. When a portion of the basin is below the outlet it serves as a catchment basin for sediment. This is not a feature that has given trouble with any of the

reservoirs described, however, as the water usually flows through their inlets at a low velocity.

The forms of embankments vary to a considerable degree. The usual practice is to make the inside slope rather flat and the outside slope comparatively steep. It will be seen that the inside slopes vary between 2 to 1 and 5 to 1 and the outside slopes between $1\frac{1}{2}$ to 1 and 3 to 1. The inner slopes of embankments have a tendency to become flat when exposed to wave action, and unless they are well riprapped with stone they should not be made as steep as the outside slope. The pressure of still water is perpendicular to any surface, and when the inner slope is flat the pressure approaches a vertical pressure on the embankment, while if it is steep the pressure approaches a horizontal thrust. Earthen embankments usually settle 10 or 12 per cent when first built, and it has been the custom to build them several feet higher than is necessary as an allowance for settling.

The additional height of embankments above high-water mark given for safety varies from 1 to 12 feet, and depends upon the height of the embankment, the area of water surface across which waves travel, and the position of the embankment relative to prevailing winds. The dam of Fossil Creek Reservoir is the only one with the exceptional height of 12 feet above high-water level, 6 feet being ordinarily considered sufficient. Most of the embankments are riprapped with loose stone extending over their entire inner face, although where the slope is not steep riprapping is necessary only near the top. When the water level is low there is no such danger of waves destroying the embankment as there is when a reservoir is full.

The outlet works of the reservoirs described represent several types. In some the position of the gate is at the upper end of the conduit, notably in the Windsor and Lone Tree reservoirs; and in a few cases the gates are operated from towers built out in the water, notably those of Lake Loveland and Mariano reservoirs. Experience has shown, however, that it is safe to place gates in the embankments, and towers, such as are shown in fig. 6, page 56, are unnecessary. The gate is never placed at the lower end unless the outlet consists of iron pipe, with the sections bolted together, as in the case of the older North Poudre reservoirs, for other materials used will not stand the pressure of the water on them when the reservoirs are full.

The usual form of conduit is of masonry, either arched on top or covered with flagging. It is always necessary to use flagging sufficiently thick to support the weight of the embankment on top of it. For the same reason short spans are to be recommended. Water naturally follows seams between different materials, and to prevent its working its way along the outside of the conduits masonry or concrete collars have been found very effective. For the same reason it is advisable to break the hard natural surface of the ground before

constructing an embankment, so that the two will knit together without a distinct seam. Concrete has proven to be excellent as a foundation for outlet works and as a floor for conduits.

The outlet should be large enough to discharge the greatest amount of water that it is desired to draw off at any time. The amount discharged through an outlet decreases with the head of water above the conduit, and an outlet just large enough to supply a certain desired amount when the reservoir is full will be inadequate when the water level is lowered. The discharge decreases as the length of the outlet increases, and where outlets are as long as that of Lake Loveland the length has considerable effect. The discharge also depends in a measure on the form of the outlet, a round conduit giving the greatest discharge for the area of its cross section. The roughness of the conduit also has the effect of decreasing the discharge, but the friction is so indefinite that the computed size for an outlet should not be relied upon, it being best to make it amply large.

Both wooden and iron gates are used. Wooden gates should not be made to fit too tightly in the grooves in which they slide, for wood swells when it is wet, causing the gates to bind. Grooves are necessary only to hold the gate in position over the outlet, and do not need to be designed with the idea of making the gate water-tight. All that is necessary is that the surface of the gate and the frame on which it slides fit closely, for the gate will be held against the frame by the pressure of the water. Iron gates working in brass grooves are found to be very satisfactory. The brass is comparatively soft, and the sliding is easier than in iron grooves.

Where reservoirs are filled to a considerable depth, the pressure on the gates is so great that very powerful lifting devices are required to move them. The simple screw is the most common arrangement, although sometimes the mechanism consists of a combination of the screw-and-worm gear or other devices for multiplying power. Any arrangement under water should be as simple as possible, for the iron parts rust, and if any accident occurs it is difficult to make repairs until the reservoir is emptied. When iron or steel rods are used as gate stems, it is necessary to brace them to prevent buckling when the gates are being forced down. Wooden stems work satisfactorily.

Wasteways are provided for reservoirs only when they are situated in running streams or have high embankments. Where they are filled through inlet ditches with the proper head gates, the supply can be easily regulated to prevent overflow.

The necessity of making large reservoir inlet ditches is coming to be recognized. As the number of reservoirs increases the available supply of the streams becomes more nearly all appropriated, and reservoirs having late priorities must have inlets large enough to take the flood waters while they last in order that these reservoirs may be filled. It is not expected that some of the later reservoirs will be filled

every year, for the limit on both streams under consideration for a season of ordinary water supply is nearly reached, and the proposed reservoirs are now known as flood reservoirs. In order that the entire supply of the streams may be put to a beneficial use, all reservoir inlets should be large, for while the total storage capacity may equal the volume discharged by the streams during all the seasons, it it can not all be saved if at any one time the discharge of the stream exceeds the combined capacities of all the inlets. Even should this condition prevail, it might so happen that certain reservoirs were already full and that the inlets of the remaining ones would not carry all the water in the streams during a flood.

LAWS GOVERNING STORAGE AND EXCHANGE OF WATER.

The general irrigation law passed in 1879 provided that persons desiring to construct and maintain reservoirs might take from the streams of the State for storage purposes "any unappropriated water not needed for immediate use for domestic or irrigating purposes," construct inlet and outlet ditches, and condemn lands for the reservoirs and ditches in the same manner as for right of way for ditches. A law passed in 1901 makes more emphatic the provision that direct irrigation has first call on the water supply by stating that "the owners or possessors of reservoirs shall not have the right to impound any water whatever in such reservoirs during the time that such water is required in ditches for direct irrigation or for reservoirs holding senior rights." This law leaves available for storage the water carried by streams in excess of the volume required by the ditches taking water direct to the fields, and the flow of the streams during seasons of the year when irrigation is not going on.

Reservoirs may be built in the channels of streams, but they are subject to the same restrictions as others regarding storing water when it is needed for direct irrigation and therefore must maintain the natural flow of the stream. In order to enable the irrigation officials to be sure this is being done, such reservoirs must be surveyed so as to show their capacities at each foot of depth and gage rods must be established. The State engineer may waive this requirement and require only measuring flumes or weirs. Owners of reservoirs may turn stored water into the streams of the State and retake it below, less a reasonable percentage for loss in conveyance from the reservoir to the place of use.

Owners of reservoirs are liable for damage caused by leakage, overflow, or breaks in embankments.

Rights to store water are adjudicated by the district courts in the same way as other water rights, and are enforced by the regular irrigation officials.

The exchange of water which has been referred to in the descriptions of some of the reservoirs is an important feature of reservoir

operation, for upon it depends the success of many of the systems of reservoirs now in use. Most of the reservoirs are so situated that they can not be both filled by and emptied into the same canal. A system of exchange has therefore been inaugurated, which was the outcome of necessity, just as the storage of water was. At first the exchange of water was neither regulated nor prohibited by any law of the State, and the arrangements were simply mutual agreements between the several parties, and as uninterested parties were not affected no objections were made. In 1897 a law was passed regulating the exchange of water. Reservoir owners are permitted to run water from their reservoirs into ditches below or into natural streams for the use of other appropriators, and to take in exchange from the stream farther up an equal amount less a certain percentage, determined by the State engineer, to be deducted for loss. The parties desiring the exchange are required to construct and maintain devices for measuring the stored water run into a ditch or stream, and it is the duty of water commissioners to measure the water and oversee the exchange.

SUMMARY OF RESULTS.

The usual time for using stored water in the Cache la Poudre and Big Thompson valleys is between the middle of July and the middle of September for the irrigation of potatoes, sugar beets, cabbage, onions, fall wheat, and the third crop of alfalfa. While water is used to some extent directly from the rivers in irrigating these crops, water is as often drawn from the reservoirs in the earlier season for the irrigation of other crops. It is therefore considered that these crops are the result of the stored water, since they could not be matured without it. Potatoes and sugar beets are the main crops, and they depend almost entirely on stored water. The entire discharge of the Cache la Poudre for August and September, 1901, was less than one-half the volume stored in the reservoirs. Three reservoirs on the Big Thompson hold more water than the stream has discharged between July 15 and September 1, on the average, for the past eight years. Without the reservoirs it would be impossible to raise the most valuable crops.

Greeley has almost a national reputation for its potatoes, although the potato district is by no means confined to its immediate vicinity; Loveland is known by its berries and small fruits, and onions and cabbage have long been successfully raised, but not until 1901 were sugar beets raised. Sugar beets, like potatoes, require late water. The Loveland sugar factory was constructed in 1901 and received 66,000 tons of beets that year from the north-central portion of the State. The next year factories were constructed at Greeley and at Eaton, and with the beginning of 1903 work was commenced on another at Fort Collins.

The crop returns for the season of 1901 were somewhat above the average. The yields of the crops though not excessive were fair, but prices were high, which made more than an average profit to the farmers. On the other hand, the season of 1902 was probably the most disastrous in the history of the two valleys. The water supply was almost, if not quite, the smallest since irrigation began. A hailstorm greatly damaged potatoes and sugar beets, especially about the town of Eaton, where there is some of the best land in the valleys. But one of the most unfortunate occurrences for the crops was a severe frost early in September at a critical period in the growth of potatoes. If the returns of the two seasons were averaged the result would be below the usual yield.

In 1901 the average price paid to the farmers for potatoes was $1.25 per sack. One sack contains approximately 2 bushels, or from 110 to 115 pounds. Cabbage was worth 75 cents per 100 pounds and onions $1.50 per 100 pounds. Wheat brought 80 cents per bushel and alfalfa $3.50 per ton. The sugar company at Loveland contracted to pay $4.50 per ton, delivered, for sugar beets for three years.

Six thousand five hundred acres of potatoes were irrigated from the Cache la Poudre Reservoir, the average yield being 85 sacks per acre. The value of this potato crop was $690,625. One right in the reservoir rented for $90. If all the 375 rights had rented at this rate the total income from the reservoir would have been $33,750. Deducting $1,000, the expense of maintenance, there remains $32,750 as a net income from an investment of $105,000, or 31 per cent. One right in the Cache la Poudre Reservoir is held at $650, and the whole reservoir is worth $243,750 on this basis.

From the Larimer and Weld Reservoir 3,720 acres of potatoes were irrigated, yielding an average of 95 sacks per acre. Therefore, the total number of sacks was 353,400, which, at the average price for the season, were worth $441,750. This reservoir cost $69,978.31. The price of one of the 186 rights was from $1,200 to $1,300 in 1901 and from $1,200 to $1,400 in 1902. The total value of the reservoir is estimated at $241,800.

It is estimated that 6,250 acres of potatoes were irrigated from the Windsor Reservoir. The average yield per acre was 25 sacks, giving $195,312.50 as the total value of the crop. One right in the reservoir irrigates 25 acres of potatoes. One hundred and fifty acres of sugar beets were irrigated from the reservoir with an average yield of 12½ tons per acre, making the whole crop worth $8,437.50. Three-fifths of the Windsor Reservoir sold in 1902 for $100,000. On that basis its whole value is $166,667, or more than three times its cost of $50,000.

The number of acres of potatoes irrigated from the Water Supply and Storage Company's reservoirs in 1901 was 5,500, on which the average yield was 90 sacks per acre. A single right in these reservoirs irrigated 11 acres of potatoes. Stored water was also used on the third crop of alfalfa.

The total number of acres irrigated under the North Poudre system in 1901 was 2,863, of which 1,500 acres were in alfalfa, 600 acres in wheat, 400 acres in barley, 100 acres in oats, 200 acres in natural hay, 30 acres in potatoes, 30 acres in sorghum, and 3 acres in sugar beets. Two hundred acres of alfalfa were left for seed and the rest produced 2,600 tons, worth $9,100. Wheat averaged 28 bushels per acre. All the crops used stored water.

The water stored in Lake Loveland and the Seven Lakes Reservoir in 1901 was used on 2,100 acres of potatoes, the average yield being 80 sacks per acre. The total number of sacks was 168,000, with an estimated value of $210,000.

Six acres of potatoes under Lake Loveland sold for $1,380 and 40 acres irrigated from Lake Loveland and the Seven Lakes Reservoir yielded 4,530 sacks of 100 pounds each. One hundred and sixty acres of potatoes irrigated from these reservoirs yielded 100 sacks per acre, which brought a cash return of $125 per acre. Eight hundred acres of sugar beets were irrigated under the Loveland and Greeley Canal, with an average yield of 15 tons per acre. Three reservoir rights in Lake Loveland was the sole dependence of 92 acres of sugar beets near Loveland. The cost of production was $4,800, which includes $12 per acre paid for the removal of alfalfa roots. The net profit was $4,200.

Fall wheat was one of the largest crops under the Home Supply system in 1901. It is estimated that there were 3,000 acres. The average yield per acre was 42 bushels. The number of acres in sugar beets was 500, on which the yield averaged over 15 tons per acre, and was larger than for any other system on either the Big Thompson or Cache la Poudre. The average profit to the farmers under the system on sugar beets was $40 per acre. Potatoes averaged 150 sacks per acre, but the acreage under the system in this crop was small.

Under the Little Thompson Reservoir complete statistics regarding the potatoes grown were gathered in 1901. The total number of acres was 96, and the total number of sacks was 1,079, making an average of 135 sacks per acre. The best average was 187 sacks per acre on 15 acres, and the lowest was 90 sacks per acre on 25 acres. Some water from the reservoir was also used on wheat and alfalfa, and the average yield for the former was 30 bushels per acre, and for the latter 4 tons per acre. There was never a paying crop on these same lands until after the construction of the reservoir.

Loveland Lake furnishes water for about 2,000 acres of some of the best land under the Handy Ditch. Fall wheat is the largest crop, but the yields in 1901 were not so great as for the same crop under the Home Supply Canal. About 800 acres are irrigated from the Welch reservoirs, Nos. 1, 2, and 5.

In 1902 the average price of potatoes was 60 cents per sack. The Greeley sugar factory agreed to pay $4.50 per ton, delivered, for sugar

beets for a term of five years, and the Eaton factory contracted to pay $5 per ton for the beets for three years.

In 1902 about the same number of acres of potatoes was irrigated from the Cache la Poudre Reservoir as in 1901. The average was 40 sacks per acre. One field near Windsor averaged 80 sacks per acre.

Potatoes irrigated from the Larimer and Weld Reservoir averaged from 30 to 35 sacks per acre on a slightly less acreage than the former season. Sugar beets irrigated from the reservoir averaged 13 tons per acre. Crops under this system did not suffer so much in 1902 as those under other systems on account of the good supply of stored water. Potatoes averaged 50 sacks per acre, except at the lower end near Eaton. Wheat under this system averaged 40 bushels per acre.

The Water Supply and Storage Company sold 90,000,000 cubic feet of stored water from their reservoir for $9,000, or $4.36 per acre-foot. One right in the company is valued at $2,250. On this basis their system is worth $1,350,000. At least one-half of this should be attributed to the storage system, which cost only $110,052.

No potatoes were raised under the North Poudre system. The total number of acres under cultivation was 3,200, of which 2,500 acres were in alfalfa. The North Poudre Irrigation Company sold 27,000,000 cubic feet of water from their reservoirs in 1902 for $2,700, or $4.36 per acre-foot.

The average yield of potatoes under the Loveland and Greeley Canal was 35 sacks per acre. Eight hundred acres of beets were irrigated, averaging 13 tons per acre. Fall wheat under the upper portion of the canal near Loveland averaged 40 bushels per acre.

In 1902 the fall wheat gave way largely to sugar beets under the Home Supply system, there being 3,000 acres of the latter. The average yield was 13 tons per acre and the entire crop was worth $195,000. The average for fall wheat was 30 bushels per acre.

In 1901 one share in the Home Supply Company sold for $90, but in 1902, on account of the increasing demand for water for sugar beets, it advanced to $125 and $150. The system is valued at $300,150, of which two-thirds may be attributed to the reservoirs. One share rented for $12.50 in 1901, but in 1902 the price was $20 in the latter part of the season. If all the shares were rented at the latter figure, the income would be $400,200. The cost of the reservoirs was only $25,500.

All crops under the Little Thompson Reservoir used the stored water. The average yield of wheat was 42 bushels per acre, of alfala 3 tons per acre, of oats 45 bushels per acre, of barley 45 bushels per acre, of onions 300 bushels per acre, and the only tract of sugar beets produced 22 tons per acre.

The water drawn from Loveland Lake was used on 1,500 acres of fall wheat, 350 acres of sugar beets, and some potatoes. The yields

of all were fair, that for the wheat being 30 bushels per acre. Wheat on one farm irrigated from the Welch reservoirs yielded 35 bushels per acre. There are approximately 2,400 acres under the Farmers' Irrigating Canal, and all the late crops would have been lost had it not been for the Lawn Reservoir.

Produce dealers estimate that 6,500 carloads of potatoes are shipped from Greeley annually, valued at $350 per car, or having a total value of $2,275,000. The value of the same product shipped from Loveland is claimed to be $20,000 annually. Potatoes are usually sold by the farmers in the sack. It is estimated that the average yield for the Cache la Poudre Valley in 1901 was 85 sacks per acre. In 1902 the average was probably not over 40 sacks per acre.

The number of acres of sugar beets raised for the Loveland factory in the Big Thompson Valley in 1901 was 2,300 and in the Cache la Poudre Valley 1,200. The average yield for the former was 15 tons per acre and for the latter 13½ tons per acre, giving the total number of the sugar beets on the Big Thompson as 34,500 tons and on the Cache la Poudre 16,200 tons. The crop on the Big Thompson was worth $155,250 and on the Cache la Poudre $72,900. In 1902 the same factory received a total of 115,000 tons of sugar beets—60,000 tons, worth $270,000, coming from the Big Thompson and 30,000 tons, worth $135,000, from the Cache la Poudre. One tract of 15 acres produced an average of over 32 tons per acre. The value of this crop was $144 per acre. The total number of acres of sugar beets raised in the Cache la Poudre Valley in 1902 was 8,500. It is estimated that the Greeley factory received 35,000 tons. A large part of these were raised under the Cache la Poudre No. 2 and No. 3 canals. The crop averaged 10 tons to the acre.

The estimate of the quantity of beets received by the Eaton factory in the same year was 20,000 tons. Most of these were raised under the Larimer and Weld and Larimer County canals, and on account of the hailstorm in the vicinity of Eaton the average yield was probably not over 8 tons per acre.

In 1901 onions averaged 200 sacks per acre. Five acres of onions near Greeley produced 1,920 sacks, which sold for $1.15 per 100 pounds. Another 5-acre tract produced 1,200 sacks, which sold for $2 per 100 pounds. One farm near Fort Collins produced 300 sacks per acre.

The produce dealers estimate that 350 cars of onions were shipped from Greeley in 1902 and that the average yield for the district was 135 sacks per acre. In this year 14 acres on one farm produced 6,000 sacks, and 4½ acres of the same tract produced 2,104 sacks, averaging 110 pounds per sack.

Cabbage yielded 20,000 pounds per acre in 1901. Two hundred and fifty cars were shipped from Greeley in 1902, when the average yield was 10,000 pounds per acre. One tract produced 30,000 pounds to the acre.

Alfalfa averaged 5 tons per acre in the Cache la Poudre Valley in 1901, but only the third cutting can be attributed to the stored water.

It is estimated that from 15,000 to 18,000 crates of berries, worth $25,000, are shipped from Loveland annually. The value of apples shipped from the same place is estimated to be $10,000. There are 1,500 acres of fruit trees in the Cache la Poudre Valley, which were irrigated as early as March 1 and frequently after September 1. Before stored water was available for orchard irrigation many trees died each year.

In a few cases in 1902 stored water sold for $150 per million cubic feet, or $6.53 per acre-foot, although this charge was excessive. The common price in that year was $100 per million cubic feet, or $4.36 per acre-foot. If all the reservoirs were filled on this basis, the stored water on the Cache la Poudre would be worth $428,000 and on the Big Thompson $173,000.

The best estimates give $1,000,000 as the worth of the reservoirs to the Cache la Poudre Valley each year and $500,000 as the worth of those in the Big Thompson Valley each year.

The following tables give the depth, areas, capacities, cost, and cost per acre-foot of storage capacities for the principal reservoirs on the Cache la Poudre and Big Thompson rivers. It is obvious that the average cost of construction per acre-foot for the reservoirs is but little more than the highest selling price of 1 acre-foot of stored water in 1902.

Reservoir data on Cache la Poudre River.

Name of reservoir.	Owner.	Depth.	Area.	Capacity.	Cost.	Cost per acre-foot.
		Feet.	*Acres.*	*Acre-feet.*		
Cache la Poudre	Cache la Poudre Reservoir Co.	31	600	8,035	$105,000	$13.07
Larimer and Weld	Larimer and Weld Reservoir Co.	31	470	6,887	69,978	10.17
Windsor	Windsor Reservoir and Canal Co.	30	700	11,708	50,000	4.27
Rocky Ridge	Water Supply and Storage Co.	30	226	4,726		
Long Pond	do	29.5	230	3,922		
Nos. 2 and 3	do	11	128	1,026		
No. 4	do	19	83	996	50,000	4.11
Lindenmeier Lake	do	8	106	716		
Curtis Lake	do	9	113	778		
Chambers Lake	do	11	180	1,259	60,052	47.70
No. 1	North Poudre Irrigation Co.	14	80	674	3,000	4.45
No. 2	do	25	300	5,000	7,500	1.50
No. 3	do	26	155	2,550	5,000	1.96
No. 4	do	15	147	1,074	5,000	4.66
No. 5	do	20	495	5,740	2,000	.36
No. 6	do	30	572	11,478	13,000	1.13
Coal Creek	do	.....	175	4,477	6,000	1.34
Fossil Creek	do	38	705	11,478	160,000	14.22
Douglas	Poudre Valley Reservoir Co.	30	586	10,547	50,000	4.74
Warren Lake	Warren Lake Reservoir Co.	8	187	689	a8,000	a11.61
Claymore Lake	Pleasant Valley and Lake Canal Co.	.....	69	896	a2,000	a2.23
Windsor Lake		6	160	689	1,000	1.45
Wood	A. J. Eaton	.....	160	2,755	2,000	.73
Lake Lee	Larimer and Weld Irrigation Co.	8	67	321	a1,000	a3.12
Total		.....	6,694	98,421	654,530	.....
Average		20.5	.....	.....	.....	6.99

a Estimated.

Reservoir data on Big Thompson River.

Name of reservoir.	Owner.	Depth.	Area.	Capacity.	Cost.	Cost per acre-foot.
		Feet.	*Acres.*	*Acre-feet.*		
Lake Loveland	Greeley and Loveland Irrigation Co.	40	492	13,212	$125,000	$9.46
Lone Tree	Consolidated Home Supply Ditch and Reservoir Co.	16.5	640	9,002	15,000	1.67
Mariano	do	16.5	373	4,140	10,500	2.54
Seven Lakes, No. 1	Seven Lakes Reservoir Co	28	65	1,148	10,000	8.71
Seven Lakes, Nos. 2-7	do	6	585	2,779	30,000	10.80
Loveland Lake	Loveland Lake and Ditch Co.	19	160	1,722	13,000	7.55
Welch, Nos. 1, 2, and 5	C. C. Welch	16	208	2,948	a 8,000	a 2.72
Big Cut	Big Cut Lateral and Reservoir Co.	20	76	1,142	a 10,000	a 8.76
Lawn	Farmers' Irrigating, Ditch, and Reservoir Co.	12	100	992	12,000	12.10
Little Thompson	Little Thompson Reservoir and Water Supply Co.	31	100	987	18,000	18.24
Ish Lake	Boulder and Larimer Ditch, Reservoir, and Manufacturing Co.	20	280	1,722	a 15,000	a 8.71
Total			3,079	39,794	266,500	
Average		20				8.29

a Estimated.

CONCLUSIONS.

Stored water has produced far more satisfactory results than would have been realized from direct irrigation alone. It is the most valuable water because it is used on the most valuable crops, and justifies investments in storage works giving a high cost for the volume of water stored.

Simple and substantial works are the most efficient, and earthen embankments, uniform throughout, are especially adapted to the general type of reservoir used in the locality where this investigation was made.

Reservoir inlets should have large carrying capacities, in order that the greatest amount of water may be stored.

The most desirable manner of operating private storage works is by cooperation on the part of the irrigators who use the stored water.

It is necessary for the public welfare that rights to water for storage, as well as those for direct irrigation, should be well established.

In one case, where a reservoir has been constructed in the channel of a natural stream supplying appropriations for both storage and direct irrigation, more or less trouble has been experienced, which would seem to indicate that reservoirs of this class are not so well adapted for private construction.

The success of the irrigators on the two streams where the studies have been made suggests what might be accomplished in other localities, for while it is true that the valleys of the two streams are particularly suited to the building of reservoirs some of the works have had to be constructed at a great expense, and still they have been highly profitable.

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LIST OF PUBLICATIONS OF THE OFFICE OF EXPERIMENT STATIONS ON IRRIGATION—Continued.

Bul. 124. Report of Irrigation Investigations in Utah, under the direction of Elwood Mead, chief, assisted by R. P. Teele, A. P. Stover, A. F. Doremus, J. D. Stannard, Frank Adams, and G. L. Swendsen. Pp. 336. Price, $1.10.

Bul. 130. Irrigation in Egypt. By Clarence T. Johnston. Pp. 100. In press.

Bul. 131. Plans of structures in use on irrigation canals in the United States, from drawings exhibited by the Office of Experiment Stations at Paris, in 1900, and at Buffalo, in 1901, prepared under the direction of Elwood Mead, chief. Pp. 51. In press.

Bul. 133. Report of Irrigation Investigations for 1902, under the direction of Elwood Mead, chief. Pp. 266. In press.

FARMERS' BULLETINS.

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Bul. 158. How to Build Small Irrigation Ditches. By C. T. Johnston and J. D. Stannard. Pp. 28.

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